ON THE WAY TO A PHILOSOPHY
OF SCIENCE EDUCATION

by

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ABSTRACT

This Thesis argues the case that a philosophy of science education is required for improving science education as a research field as well as curriculum and teacher pedagogy. It seeks to re-think science education as an educational endeavor by examining why past reform efforts have been only partially successful, including why the fundamental goal of achieving scientific literacy after several “reform waves” has proven to be so elusive. The identity of such a philosophy is first defined in relation to the fields of philosophy, philosophy of science, and philosophy of education.

Considering science education as a research discipline it is emphasized a new field should be broached with the express purpose of developing a discipline-specific “philosophy of science education” (largely neglected since Dewey). A conceptual shift towards the philosophy of education is needed, thereto, on developing and demarcating true educational theories which could in addition serve to reinforce science education’s growing sense of academic autonomy and independence from socio-economic demands. Two educational metatheories are contrasted, those of Kieran Egan and the Northern European Bildung tradition, to illustrate the task of such a philosophy. Egan’s cultural-linguistic metatheory is presented for two primary purposes: it is offered as a possible solution to the deadlock of the science literacy conceptions within the discipline; regarding practice, examples are provided how it can better guide the instructional practice of teachers, specifically how it reinforces the work of other researchers in the History and Philosophy of Science (HPS) reform movement who value narrative in learning science.

Considering curriculum and instruction, a philosophy of science education is conceptualized as a “second order” reflective capacity of the teacher. This notion is aligned with Shulman’s idea of Pedagogical Content Knowledge. It is argued that for educators the nature of science learning must be informed by a critical examination of curriculum which takes into account the demands of educational metatheory but also the nature of science and nature of language. Two philosophy of science education case studies linked to the latter two are offered: the realism/instrumentalism debate, and the scrutiny of Dewey’s language views from a Gadamerian hermeneutic perspective.
Keywords: Science Education; Physics Education; Science Education Reform; Scientific Literacy; Philosophy; Philosophy of Education; Philosophy of Science; Curriculum Theory; Educational Theory; Metatheory; Bildung; Pedagogical Content Knowledge; Constructivism; Nature of Science; Epistemology; Language Theory; Cognitive Tools; Narrative; Hermeneutics; Kuhn; Gadamer; Dewey; Egan
Dedication

This work is dedicated to
my wife,
Elke

who has been an unfailing source of love, support and encouragement throughout
the many years in which this Thesis came into being

and to my two sons,
Armin and Kai

I thank them for constantly reminding me of the nature of the educative process
through their sense of wonder of the world around them, their questions and desire to
know, but especially their joy of exploration and play, and flights of imaginative fancy.
May you always be fascinated by questions and endure the quest for understanding.
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There have also been a few other individuals whom I wish to explicitly mention who have made significant contributions to my own intellectual development and who have left their mark in one way or another on this Dissertation. Dr. Kieran Egan has been very helpful with encouragement, insight and various critical comments which have contributed to the eventual publication of some chapters. Dr. Michael Matthews of Australia (University of New South Wales) has been very supportive and I wish to acknowledge the stimulating intellectual environment of the International History, Philosophy and Science Teaching group (IHPST). As a former Graduate Student Representative serving on the Executive Council I had the privilege of observing the organization become officially established. The valuable presentations and new-found friendships at the conferences have enriched my beliefs and views of science education.

I am also grateful to Dr. Mark Battersby (Capilano University), mentor, fellow philosopher and friend, for many fruitful discussions on science and philosophy, for his encouragement and critical comments on some chapters. Finally, thanks are owed to my life-long friend, Dr. Don Lint, scientist and physician, for our countless conversations on life, science, philosophy and religion with many a fine cigar and cognac.
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CHAPTER ONE: Introduction. Making the Case for the Philosophy of Science Education: Surveying the Terrain

“It was through the feeling of wonder that men now and at first began to philosophize”

—Aristotle (Metaphysics)

What sort of thing is a “philosophy of science education”? As implied by the included subjects, is it more concerned with philosophy, or with science, or with education? Then again, is it intended to focus more on problems in philosophy of science, or philosophy of education as related to learning science? Moreover, can it be undertaken, this “philosophy”—one that purports to be a philosophizing of science education? What would comprise its scope and tasks? And who would undertake it?

Science education has roots going back over a century, although as a discipline and research field it is relatively new, only having come into its own in the US since the 1920s (National Association of Research on Science Teaching NARST, created in 1928), arguably perhaps only since the “Sputnik shock” of 1957 and the professionalism which followed. It is admitted that Physics Education Research (PER) and Chemistry Education Research (CER) are newer still, barely thirty years old. These two research fields, and as very new disciplines—if they can even be called that—are still finding their way among their respective academic departments at some universities (for their true worth is not yet universally acknowledged). Yet despite its longer history some would argue science education is still developing an identity (see Fensham, 2004). What would comprise the role of a “philosophy of science education” (PoSE) for science education, especially in light of establishing its identity? What would its value be—assuming it had one—and what could it contribute?

To anticipate: a philosophy of science education is foremost a philosophy and as such receives its merit from whatever value is assigned to philosophy as a discipline of critical inquiry. (This value may not appear at all obvious to science educators). Furthermore, such a philosophy would need to consider issues and developments in the history, sociology and philosophy of science, and analyze them for their appropriateness for improving learning of and about science. Finally, such a philosophy would need to
consider issues and developments in the philosophy of education and curriculum theory, and analyze them for their appropriateness for education in science, as to what that can mean, how it could be conceived and best achieved. It ultimately aims at improving science education as a research field as well as assisting teachers in broadening their theoretical frameworks and enhancing their practice.

1.1. The Relation to Philosophy
As the title implies, the topic and theme of this thesis is one that concerns a search, a looking for, a route to a destination. It is quite common to distinguish the path from the goal itself. When the goal is known ahead of time, for instance climbing to a known craggy summit, one often has various options of choosing which path might prove the most expedient, or the most beneficial (or perhaps both), to arrive at the desired destination. Depending upon one's own predispositions, one may even be willing to make that extra effort if the path is known to be arduous but the view from the summit known to be spectacular. But what if the destination is a new one, the path barely trodden, the goal shadowy and the summit shrouded in mist? The route to be taken becomes much more difficult to make out, and the effort questioned. Pioneers are then ridiculed as fools or later lauded as visionaries depending upon their respective failure or success. In either case there are risks involved. This Dissertation is such a risk, it implies such an endeavor. Why? Because the position taken here is indeed new: that science education both as academic inquiry and as a field of practice requires the development of an in-house philosophy in order to execute effective reforms and progress as a discipline.

The risk is that, as with all things new and especially with educational matters, one is at first startled and curious, but soon one begins to question the value and relevance if no immediate practical applications can be discerned. Indeed the harsh utility criterion has come to serve as a predominant tribunal of judgment for new reform ideas and efforts in science education, of which, it can be sadly admitted, there have been too many in the last 100 years, several in the last 50 years alone. Some teachers and researchers may view this as a good thing, since it functions as a rule-of-thumb (certainly from the perspective of practitioners) of filtering well-meaning but abstract academic (or "top-down") initiatives which appear for most classroom purposes unproductive.
Undoubtedly when the topic of philosophy is broached this complaint commonly arises. One can understand a teacher who asks: "What does philosophy have to do with science?" Or more succinctly and less pejoratively: "how can any sort of 'philosophy' contribute to helping my students better understand difficult scientific concepts?" Such questions of course, implicitly assume a deep divide between science and philosophy, certainly between science education and philosophy, and exposes much about typical teacher training and the nature of science textbooks. (Yet it is exactly this sort of question with the teacher in mind that Scheffler had already addressed decades ago in 1970). That said, one must concede the serious problem for science education today (and education in general) as the on-going gap between university-based research and classroom applications—not just pertaining to 'pure' academic subjects like philosophy—arising for different reasons, and which continues to occupy the concern of the research community (Boersma et al., 2005; Millar et al., 2000). Yet even if one has begun to recognize the value of philosophy, or perhaps better put as appreciating critical thinking and philosophical analysis for curriculum development and for one's own practice—which it seems to me many experienced teachers eventually come to admit—there remains the issue whether one thinks science education itself requires such an encompassing philosophy as a constituent goal, as something required of its self-conception, to help it "mature" and better able to develop as an autonomous discipline. And even if this much is admitted, one may still question the route to get there, and hence the feasibility of ever accomplishing anything so grand.

Philosophy has always entailed certain risks, as the lives of Socrates and Aristotle in antiquity, Giordano Bruno and Rousseau at the start of the modern age, or more recently Hannah Arendt and Karl Jaspers, exemplify. With the establishment of academic philosophy at the universities in the 19th century, most risks have been thankfully mitigated, but risks remain today albeit of a less ominous kind. It has also been historically associated since at least the time of Nietzsche with the metaphor of climbing heights if for no other reason than attaining clarity, a better overview of the metaphysical landscape (or scientific or political, etc.), and possibly of attaining a new vision. The premise of the Thesis is the necessity of both for improving science education. In other words, the need to re-examine and re-think the common problems of the science
educational terrain—associated with goals (especially science literacy), curriculum, learning issues, nature of science and language—from a fresh perspective and with the intent of providing solutions offering new ideas, new research pathways and possibly a new vision.

Some may think this task is too bold, or too complex, and probably unachievable. Such a summit was never before in sight, such a venture never before offered, and therefore not required—others warn that although such a summit may be in view, the climb is impractical and hardly worth the effort. Besides, have not the tremendous achievements of science left behind the endless chatter of the philosophers? Moreover, does not philosophy itself provide abundant grounds to be cautious and less lofty? One should not overlook, as skeptics will be keen to remind us, that philosophers over the ages have tended to promise more than they have delivered, and history bears ample witness to the collection of constructed and cast off philosophical systems (from Plato to Aquinas, from Descartes to Kant, Hegel and Marx). Nietzsche was among the first (along with Kierkegaard) to be rightly critical of “systems” and argued against their attempted project. In our time, in the wake of the collapse of foundationalism generally, including the linguistic-based logical positivism of the English-speaking world, Wittgenstein, Rorty, Taylor, and others have accepted this attitude and arrangement as the new philosophical status quo. Continental philosophers such as Heidegger, Gadamer, Derrida, Habermas and Foucault, arriving at similar conclusions in appraising the Western tradition, have afterwards gone in different directions, but some in parallel with American pragmatism. The tremendous wake has left behind many troubling questions among philosophers, now widely known, such as what the contemporary role of epistemology should be (with related ramifications for philosophy of science). And above all, if philosophy itself—understood as philosophy with a capital “P” as Rorty puts it, the age-old conflict between “Platonists” and “positivists” to achieve the definitive appraisal of knowledge (epistemology), reality (ontology) and virtue (ethics)—has possibly come to an “end” (Baynes et al., 1987; Rorty, 1982; Heidegger, 1977).

When examining the recent quarrels among professional philosophers as to whether or not philosophy as a discipline has now finally managed to find its “proper object” and “goal”, including the right way (or “systematic methodology”) to go about
solving philosophical problems, one discovers soon enough a sharp contrast of views among adherents within the Anglo-analytic tradition, for instance spotlighting such familiar figures as Michael Dummett—who has answered in the positive—and Richard Rorty—who remains skeptical and has answered in the negative. While Dummett would front the significance of Frege in finally having helped philosophy establish its proper tasks (all the while recognizing the many previous failed historical attempts to ascertain this), Rorty would recognize instead the importance of three, namely, Dewey, Wittgenstein and Heidegger “precisely because they have helped overcome the very conception of philosophy that Dummett and so many professional philosophers accept” (Bernstein, 1983, p.6).\textsuperscript{1} Bernstein would see the contrasts between Dummett and Rorty (also between Popper and Feyerabend in the philosophy of science) as indicative of a wider cultural debate spanning other disciplines, especially the social sciences, which he identifies as the antithesis of objectivism and relativism in Western thought. In line with Rorty and others, he too would see the epistemological task of traditional philosophy coming to a close: “… we are coming to the end—the playing out—of an intellectual tradition (Rorty calls it the ‘Cartesian-Lockean-Kantian tradition’)” (ibid, p.7). He observes a “new conversation” emerging about human rationality going “beyond objectivism and relativism”, moving from epistemology to hermeneutics and praxis, or what elsewhere has been called “the interpretive turn” (Hiley \textit{et al.}, 1991). A philosophy of science education must of course be cognizant of these quarrels and developments both in philosophy and philosophy of science. First of all, to help it examine its own self-understanding as a philosophy, regarding its own tasks and what it can possibly accomplish (which will be discussed shortly), and secondly, to partake of this current “conversation”—the position taken here is that science learning can be improved if the “interpretive turn” is also recognized and valued (to be discussed in chapter five).

But to avoid misunderstanding what is suggested here is nothing even remotely comparable to “system building” or attempts to place philosophy back upon its former pinnacle position, as arbiter over the sciences—or education—as a sort of ultimate epistemological tribunal in judgment of other worldviews and knowledge claims, as it

\textsuperscript{1} “The contrast between Dummett’s and Rorty’s views indicates not only the most divergent and antithetical understandings of the accomplishment of modern and recent analytic philosophy but of the self-understanding of philosophy itself” (p. 7).
had claimed for itself since the Enlightenment era when it stole the crown from theology. It remains rooted instead in the firm ground of philosophy’s original Socratic calling, the worth of examining one’s *way-of-life* (one’s academic discipline and pedagogy), entailing conceptual analysis, critical questioning as well as cautious speculation and theorizing. This is a kind of living project that Wittgenstein, Rorty and Gadamer would subscribe to, and indeed many philosophers and teachers would go along with (granted, what is ignored in this version is the proper role of reason). Such a humble yet noble perspective of philosophy hardly commands an end, if anything it demands a *continuing*, perhaps in some sense and with respect to the topic to be examined, a new beginning.

One need not hold to any sort of Kantianism and yet concur with the great philosopher on the perennial value of philosophy and philosophical questions, when he wrote (in old age and looking back on his accomplishments), that his work had been inspired by the need to answer three basic questions: What can we know?; What should we do? What are we allowed to believe? These three questions regarding epistemology, ethical action and belief, although answered in diverse ways at different times by different thinkers, remain acute even for our contemporary age, and can just as fruitfully be phrased for the educational context concerning curriculum, teachers and learners, respectively. (Or alternatively, to address all three questions to each educational subject individually). The point here is to show the relevance of philosophy for the *inquiring mind*, even when simultaneously, and on the other hand, the *irrelevance* card is often raised because of frustration over the apparent *lack of progress* on exactly these three questions towards solutions by great thinkers in these areas of vital human concern, including education and the schools. The typical objections to philosophy as a subject preoccupied with obtuse speculation, arcane technical jargon, and unresolved disputes all remote from everyday matters are familiar and to be lamented. (In this sense it has faithfully followed in the footsteps of a theology it supplanted at the universities). Dewey

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2 Habermas takes Rorty to task for undermining the one role still left to philosophy, being the “guardian of rationality”. “If I understand Rorty, he is saying that the new modesty for philosophy involves the abandonment of any claim to reason—the very claim that has marked philosophical thought since its inception”. While Habermas agrees with Rorty philosophy must give up its assumed Kantian project of ultimate knowledge arbiter (*Platzeinweiser*), it must still “retain its claim to reason”, taken to mean stand-in (*Platzhalter*) and interpreter (1987, pp.298-9).
though, would expect from us more circumspection when philosophy wrestles with the complexities and dilemmas of those problems embedded in life (or educational) issues:

If there are genuine uncertainties in life, philosophies must reflect that uncertainty. If there are different diagnoses of the cause of a difficulty, and different proposals for dealing with it; if that is, the conflict of interests is more or less embodied in different sets of persons, there must be divergent competing philosophies. ... But with reference to what is wise to do in a complicated situation, discussion is inevitable precisely because the thing itself is still indeterminate (1916, p.327).

Such differences and disputes, moreover, Dewey sees arising from thinking which is embedded within actual social experiences and practices. This also appears to be the case concerning the central conflicts within the science education community, where researchers and practitioners are inevitably preoccupied with problems associated with different phenomena and segregated facets of the discipline. This Thesis will follow his insights on “conflicting proposals and interests” when examining the disputes over science literacy (Ch.2) understood as competing paradigms of what science education should be about. In addition, the requirement of Philosophy of Science Education (PoSE) for the science education community is advanced exactly for the reason he mentions, in my interpretation, the need for some sort of philosophical platform of “discussion” to elucidate the problem “thing” of science education reform issues.

Still, the widespread skepticism towards what philosophy can offer by way of answers and practical solutions is especially robust among the many of us—moreso teachers in the North American educational establishment—with acquired pragmatic habit of mind while living in an age accustomed to quick fixes and impressive technical results. The attitude is plain as day: is there actually any time for teachers preoccupied with overcrowded secondary curricula, stressed by high-stakes testing and worried about their students learning in diverse school cultural environments, to stop, think, and ask the essential educational questions again: “what does it mean to be educated?” (expressed very broadly)—and for our science education profession, “what does it mean to be educated in science?” (in physics, in geology, etc.?). This latter crucial question should be kept distinct from—though it often tends to be subsumed to—the question harbouring a social utilitarian criterion so prevalent among the English-speaking nations: “what do
we educate people in science for?" Are there in fact answers to these kinds of questions that can be “cashed in” for teachers and their “instrumental” stance for “what works”, but in noteworthy ways that can help transform their thinking and pedagogy? This Dissertation will show that there is. Yet what is of utmost importance is to recognize that to entertain such questions and concerns is to presume the invaluable and obligatory nature of a “philosophy of science education” for *fundamental science education reform* intending to invigorate a *discipline* concerned with curriculum development and research, teacher education and meaningful student learning of science.

There are those skeptical thinkers like Wittgenstein, of course, who once famously stated that philosophy “leaves everything as it is” (*Philosophical Investigations*, #124; in a passage where he specifically dismisses *foundationalism*), and would instead have its value reside in things other than any sort of “reform” or restructuring (for example, “therapy”, “to shew the fly out of the fly-bottle” *PI*, #309). Then again, Marx had astutely stated a good century before Wittgenstein that philosophy has only *interpreted* the world, but the point was now to *change* it—and this as a critique of the reigning academic Hegelianism of his day. And who would dare deny Marxism has not contributed, no matter how controversial, to radical intellectual and socio-political change? Or deny the horrific *adverse* alterations (both personal and communal) wrought by fascist and communist philosophies? History witnesses that philosophy is at its most transformative when it develops as a *worldview*—one thinks of Locke or Rousseau or atomism or evolution; it need not be expressly political, although it could have those ramifications—think Nietzsche or social Darwinism. (In 1919 the young Heidegger took the position that philosophy had a dual purpose with respect to worldview: the *immanent task* of philosophy is to develop one, and, alternatively, it sets the *limit* of philosophy, which must stand against it as a “critical science”; 2008, p. 9). The question of the degree to which science itself harbours philosophical worldviews, either of necessity as belonging to its epistemological or socio-cultural make-up or rather as consequence resulting from implications of its theories, is an important debatable subject—though one science teachers or the curriculum rarely entertain. Yet there are clear historical precedents (e.g. Copernican revolution; materialism; reductionism; scientism; eugenics). The attention this topic deserves in science education has only recently been addressed.
(Matthews, 2009a). Indeed, seen in this historico-political light and from our current vantage looking back at the last two centuries—in particular the devastating 20th—some may come to the opinion that it is better all round that philosophy should “leave everything as it was”. Here there is no question of the practical consequences of philosophy, or of its “usefulness”.

There is no denying we all live in an age drastically transformed just as much by the philosophical ideas of Locke, Kant, Mill, Marx and Nietzsche, as by the scientific theories of Einstein, Heisenberg and Darwin, as we are by the physical machines of turbojet, computer and all those other technological advances which more quickly come to everyone’s mind when thinking social or global change.

In the field of education, who could deny the consequences of Dewey’s philosophy, especially in the development of science education (DeBoer, 1991), although too many today are not familiar with it. For science teachers the reality of philosophy as worldview equally cannot be denied, for it pervades their subject and curriculum in the forms of objectivism, reductionism and positivism, though regrettably many will not recognize it. The argument that science teachers in particular need to become more philosophically circumspect regarding the dimensions of their own teaching (e.g. nature of authority) and about science epistemology and worldview as presented in curricula, was first raised by Roberts and Russell (1975) some time ago, yet it remains more acute than ever today (Roberts and Oestman, 1998). For instance, there are presently those among critical pedagogues, postmodernists, multi-cultural science educators and others (Aikenhead, 2002, 1997; Loving, 1996; Hodson, 1993; Lyotard, 1984), who would go much further, making sinister accusations against the Western science curriculum (if not against so-called “Western science” per se). They charge its unspoken epistemology is tainted with an ideology labeled scientism which is indisputably exclusivist and oppressive while it innocently parades as a vital knowledge tool for globalizing interests, socio-economic progress and enlightenment. Here we have two unavoidable grounds (the ‘hidden’ philosophy behind curriculum, and that it is oppressive) for arguing the necessity of a “philosophy of science education” for teachers, their profession and the academic research field in general. These reasons are certainly grave enough, and yet if such a philosophy could in addition incorporate educational discussions and meta-
theoretical dimensions which could show improvements in science conceptual understanding alone, that of itself it seems to me, would be enough to convince most science educators and researchers of the worth of the undertaking and establishment of this new inquiry field.

Let us nonetheless return to Wittgenstein’s observation and examine further the common accusation of Philosophy’s inefficualt worth, its lack of progress, its inability to penetrate the veil of existence and hence its lost status, in short, it being rather “useless”, taken to mean of little practical value. For he had uttered a skeptical statement of the task and value of philosophy that corresponds with a widely-held notion today (although he still saw its worth rather differently), to help dispel nonsense problems: “the philosopher’s treatment of a question is like the treatment of an illness”, \( PI \#255 \)—yet the problem of its practical relevance is as old as Aristotle and the thorny relation between \textit{theoria} and \textit{phronēsis} (between “theoretical” and “practical” reason) as discussed in his books. For right at the beginning of his \textit{Metaphysics} (1998), he deliberately raises this issue as to what sort of thing “philosophy” is. He contrasts the knowledge gained through experience of particular objects or events with theoretical knowledge gained \textit{from} these experiences that allow us to derive general propositions or “universals” that can go beyond them. He admits that to know particulars is invaluable, since from them comes practical action, for example, in the case of medicine to cure the real person in the concrete situation (not some general category “man”), and conversely having a mere “theoretical account” without experience often leads to error. This is the advantage of practice, and it is the view many teachers, especially pre-service teachers, would recognize and immediately share. But the truly knowledgeable, so Aristotle argues, develop expertise in both modes of either doing (\textit{technē}, as an art or skill) or theorizing (\textit{theoria}), and it is these that are generally accorded more prestige. Such status he associates with the ability of \textit{technē} and \textit{theoria} (today more commonly termed “technical” and “theoretical” reason) to having identified underlying causes and principles that usually evade the mere practitioner. In so doing he consciously asserts two value judgments, one according greater worth to reasoning and contemplation over practice \textit{and} the other defining the worth of philosophy as residing in uncovering those causes and principles as an end-unto-itself—or as I would interpret it, the \textit{search for}
understanding broadly conceived. So viewed, it retains sole intrinsic worth: “So it is clear that we seek it for no other use but rather, as we say, as a free man is for himself and not for another ... for it alone exists for its own sake” (p.9). As the translator phrased this viewpoint, “philosophy is supremely useless and supremely elevating” (p.4).

Now such a statement may sound quite absurd (and help reinforce the opinion of the irrelevance of philosophy) to the science education ear resonating with the loud tones of utilitarian intentions and avowed moral projects, especially among those reformers preoccupied with singing the goals of science education (and “literacy” conceptions) to a drumbeat of socio-utilitarian or socio-political tunes (e.g. the STS movement or “science as socio-political action”; Hodson, 2003; Roth and Desautel, 2002; Yager, 1996). Not to be misunderstood, no disparagement of such declared ventures is intended here. My point is a different one: what usually remains unacknowledged is that such sentiments and arguments assume a predetermined position for “philosophy” implicitly. The implied view taken here, as I see it, is that if philosophy is to have merit at all as a PoSE it must first of all (and primarily) perform a duty and to render service; in other words, as instrumental worth. That may indeed be one of its functions, as is currently taken on board by the “critical-emancipatory” research tradition (Kyle et al., 1992), one which relies heavily by-the-way on the Marxist-Freire-Habermasian “critical pedagogy” philosophy (and worldview; Blake and Masschelein, 2003; Apple, 1975; Freire, 1975). But whether this should be its sole role or even its best one, is exactly what needs to be determined and not assumed. This provides precisely one crucial task of PoSE, that such hidden philosophies of education must be brought to the surface and revealed as they impinge upon the purpose and identity of science education.

My own view would be, first of all, a closer alignment with the original intention of Aristotle, being the need for a search for understanding, and hence a PoSE stands on its own intrinsic merits. As Dewey wrote: “On the side of the attitude of the philosopher and of those who accept his conclusions, there is the endeavor to attain as unified, as consistent, and complete an outlook upon experience as is possible. This aspect is expressed in the word philosophy—“love of wisdom” (1916, p.324). But this is not meant to imply, as Dewey certainly would have objected, that it could not perform a dual role, to indeed serve useful functions (inclusive of the aforementioned question of duty), such
as helping better demarcate science education from psychology—with the critical appraisal of utilizing theories from other disciplines—or analyzing and clarifying science education goals (including “literacy”), among others, all of which could contribute to helping ground science education as an independent discipline. This perspective, however, must conceive of the valuation “useful” rather differently, namely, that understanding in actual fact performs quite an important practical role in-and-of itself, for it inevitably, and sometimes immediately, forces change in thinking and action. In short, the search for understanding is never “useless” (as Whitehead (1929) himself saw), only that the ways in which theoria is interwoven with techné or phronésis may not be obvious or generally foreseen.

With that admission I wish to avoid not only a misunderstanding but a danger inherent to certain perspectives of the task of any philosophy as well as the role of “theory”—both issues being identified as problems belonging to, and long exhibited in, the history of philosophy and everyday thought. My view bears much in common with the well-known positions of both pragmatism (Dewey, Rorty) and philosophical hermeneutics (Gadamer) which strongly deny any strict separation between theory and practice in reality, and which would characterize such dichotomies as artificial because mind can never be truly divorced from the communal nature of language and social activity. Rather such assumed positions as the isolation of philosophy and the divorce of “pure theory” from life or practice result instead, according to Dewey (1916), from two sources: from social strictures as well as from perceived dualisms due to the nature of thinking and experience, having occupied philosophy as problems for centuries (intellect and emotions; particulars and universals; knowing and doing; mind and body; individual and society; authority and freedom; science and arts; culture and vocation). By the former is meant those social conditions and values inherent to a society that privileges passivity and the contemplative life, and therefore elevates abstract reasoning and theorizing above practical reasoning and agency (also counting academic life above vocations).

What is here proposed, in other words, for PoSE is in the first instance to be taken as theoria as Aristotle and as Kant understood it, namely in the sense of critical reasoning but with practical import—although admittedly, the former philosopher also meant from work withdrawn, a contemplative and consummate life as the ultimate human
achievement, while the latter meant epistemology with detached sovereignty capable of objectively assessing the worth of all knowledge, beliefs and actions. Both of these evaluations have certainly come to typify modern academic as well as everyday notions of philosophy and "theory" (though it should be stressed the Aristotelian notion was communal, whereas the modern one tends to be individual-subjectivist). But one need not hold to the implied wider conceptions of these two philosophers while still maintaining that theoria understood in the widest sense could fruitfully imply an analysis and critique of all three kinds of rationality, namely, theoretical, technical (or instrumental) and practical—themselves first identified by Aristotle (Metaphysics, 1998, 1025b; p.154). Such a view does not automatically implicate one in any sort of prioritizing among them, and the temptation to do so must be resisted. For it is common now-a-days, especially with the devaluation of "theory" that has come along with Feyerabend (1975), with postmodernism (Lyotard, 1984) and with the rediscovery of "practical reason" in educational studies (see Dunne and Pendlebury, 2003) to not only contrast technical reason (techné, or production) with practical reason (phronésis)—which can have its merits—but to associate (if not mistakenly to subsume under or outright equate) scientific theory with the former, at the same time as elevating the latter at the denigration of the first. One proceeds by creating the new hierarchy: practice over theory and production (together), to supplant the antiquated Greek hierarchy of theory-practice-production. Heidegger certainly inverted this order initially, as did Dewey, but whereas the later Heidegger appears to have returned to the classical Greek schema, Dewey did not (Hickman, 2001). So the implications of the notion of theoria casts a wide conceptual and historical net, it will be acknowledged, but no such prior mentioned commitments or disputes are meant to be either implied or ignored by my use and understanding of the term theoria, or the view here taken on philosophy.

Having said this, what is proposed for a PoSE in the second instance is that its task is neither merely passive nor just critical, but also constructive:

Philosophy is not [passive] in the sense that it involves merely making explicit what was implicit in the forms of thought that have developed [contra Hegel]. Neither is it merely critical in the sense that it involves merely challenging such systems of thought. It can pass over into attempts to reconstruct conceptual
schemes and think out anew the basic categories necessary for describing the world [of science education] (R.S. Peters, 1966, p.61).

This Thesis is such an attempt to think science education anew, and to offer constructive advice utilizing “conceptual schemes” based on the metatheory of Egan (Ch.3) and the philosophical hermeneutics of Gadamer (Ch.5).

Finally, not to be forgotten, what is proposed as a third instance is that a PoSE would show its immediate practical value for the classroom by stressing the philosophical dimensions of critical thinking (e.g. science vs. pseudoscience) and scientific argumentation for student learning, topics that several researchers have previously recognized and continue to actively pursue (Osborne et al., 2004; Bailin, 2002; Matthews, 1994; Kuhn, 1993).

1.2. The Relation to Philosophy of Science

How would a philosophy of science education be related to the field of philosophy of science? Thus far we have attempted to ascertain its status as a “philosophy” and establish its location within historical philosophical developments. It probably goes without saying that any such philosophy which has as its main concern the education of persons into the disciplines of science (narrowly construed)—or better phrased, an education of the scientific enterprise (widely construed)—must consider what studies into the epistemology and nature of science (NoS) have revealed.

Here, though, we are on well-trodden ground, no matter how difficult the trek in the past has been through muddy disputed soil and foggy epistemological terrain. For there have been cases not only of historical overlap in the development between the two fields of science education and philosophy of science in the past (as there was in the case of Dewey and philosophy of education)—as examples, Mach in Europe and Phillip Frank and Robinson in America (Frank, 1957; Robinson, 1969; Matthews, 1991)—but also cases where the two fields have diverged and not taken notice of each other. It is now well-known that the well-funded and large-scale curricular reforms enacted predominately by government ministries and scientists in a “top-down” fashion in the 1950s/60s were strongly informed by an inductivist perspective on scientific methodology and science learning, which itself reflected (though not solely) the then-
reigning ahistorical positivist views in the philosophy of science. The terrain of problems associated in particular with defining scientific methodology and authentic inquiry appropriate for science classrooms and laboratory work has been recognized for some time now as especially thorny (Schwartz et al., 2004; Hodson, 1996; DeBoer, 1991).

Yet even at this time of the early 1960s when the philosophy sub-discipline was undergoing a major upheaval and shifted into a “post-positivist” phase with the works of Hanson, Toulmin, Kuhn, Feyerabend and others (Suppe, 1977), science education remained largely wedded to the older philosophy. By 1985, Richard Duschl could complain there had been “25 years of mutually exclusive developments” between the two, with science education (e.g. textbook and teacher epistemology) imbued as it was with inductivism and positivism lagging decades behind. In other words, the influence of some sort of philosophy of science was always present to some degree within science education and its changing “curricular emphases” (Roberts, 1982) in the last hundred years or so of its advancement—whether acknowledged by teachers or not—just that on some occasions in certain eras the influence of that sub-discipline was more explicit than at other times, and moreover, changes in one field take decades before they impact the other. Today at least on the academic front the situation has changed considerably. The recent revival of the history and philosophy of science (HPS) reform movement in the 1990s has now allowed for the “rapprochement” of the once separate academic disciplines of history, philosophy and sociology of the sciences with science education, but its potential has not yet been fully realized for science teacher education or science classrooms (Nashon et al., 2008; Turner and Sullenger, 1998; Matthews, 1994).

As for science teachers themselves, most have some sort of rudimentary “philosophy” of teaching their subject matter (more implied than expressed), say, keeping close to the “structure of the discipline” or, more commonly today, “teaching by inquiry”. Unfortunately, as already some earlier studies had shown, their beliefs (or as I would prefer, personal “philosophies” or epistemologies) do not often match their practice (Hodson, 1993b; DeBoer, 1991; Welch et al., 1981). Regardless, studies have shown that some image of science is either implied (if not fully recognized) or overtly taught in the way teachers use language in instruction and arrange activities to justify the nature of lab or fieldwork (Wellington and Osborne, 2001; Lemke, 1990; Tasker and Freyberg, 1985).
Students receive some lasting impression of what science is and how it is done from what is articulated and displayed in class (termed “companion meanings” by Roberts and Oestman, 1998); this is further influenced by what textbooks deliberately convey about science content knowledge and “processes” (or “method”), or other nature of science (NoS) terms (law, hypothesis, theory, etc.), including the kind of historical portrayal of the subject content (Alchin, 2003), often referred to as the “epistemology of school science” (Cawthon and Rowell, 1978).

Overall, considering what is conveyed about the nature and history of science this is done quite poorly, which is now widely recognized and been the subject of many research studies (Lederman, 2007; McComas et al., 1998). In brief, a false sense of inquiry as a universal and singular “scientific method” is disseminated (Bauer, 1992)—one of about 15 myths which have been identified to infuse school science (McComas, 1998). Moreover, in secondary and tertiary classrooms a narrow curricular focus and assessment on the “what” instead of the “how” of science—that is, a preoccupation on formal, decontextualized content knowledge (CK) organized into topic structures of specialized disciplines instead on how knowledge is obtained and confirmed along with the actual process of theory change and discovery—too often result in an image of science in static “final form” (Duschl, 1990). (A problem already identified by Dewey decades earlier as a major obstacle to science learning). This pertinent observation echoes Schwab’s (1962) prior complaint that such instruction implies science is to be understood as a “rhetoric of conclusions”, while such structures at the same time implicitly assume and project a “positivist epistemology”. Sutton (1996) has insightfully described how the language of a scientific idea changes from its initial discovery through to research paper and textbook formulation, especially how textbooks distort and mask the historicity of scientific language and theory (key educational issues first pointed out by Thomas Kuhn himself). He has argued that students’ beliefs about science are shaped by their beliefs and use of language (following Lemke, 1990), which are intimately shaped by textbook ‘talk’ and classroom conversation, reinforcing Duschl’s “final form” indictment. All these factors are said to contribute to the low levels of science literacy and the ongoing poor understanding of science among the public (Yager, 1996; Bauer, 1992).
The ability to change this particular debilitating quality of the character of science textbooks appears to be extremely limited for the foreseeable future (although exceptions exist, see the physics textbook of Holton & Brush, 2001), hence chances for improvement of HPS awareness and inclusion seem better suited to be met in the areas of teacher in-service and pre-service teacher training. Matthews (1994, pp. 204-5) writes with respect to teacher epistemology:

A teacher’s epistemology or theory of science influences the understanding of science that students retain after they have forgotten the details of what has been learnt in their science classes ... this ought to be as sophisticated and realistic as is possible in the circumstances. [Unfortunately] a teacher’s epistemology is ... largely picked up during his or her science education; it is seldom consciously examined or refined.

Interest in studying the epistemology of school science had already produced several significant prior studies (Hodson, 1985; Cawthron and Rowell, 1978; Smolicz and Nunan; 1975; Elkana, 1970), and research continues into both teacher and student epistemologies (Abd-El-Khalick and Lederman, 2000; Désautels and Larochelle, 1998; Driver et al., 1996; Meichstry, 1993; Ryan and Aikenhead, 1992), but, sadly, such studies have too often shown that an improved alignment between teacher and nature-of-science epistemologies which Matthews identified as of central importance is still far from being realized. Still, the importance of nature of science (NoS) understanding for improved student comprehension of what science is all about has been an avowed objective of science education for almost a century, and has recently been reemphasized on a global scale: all international Standards documents of the 1990s in the English speaking nations have now come to stress this dimension for policy and their school curricula (see McComas and Olson, 1998). But how effective these policy documents are remains arguable (Lederman, 2007; 1998), and for the most part teachers remain poorly prepared

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3 In their major review, Abd-El-Khalick and Lederman (2000) mention three major lines of research on NoS in the past 50 years that has proceeded in sequence. The first line investigated students’ conceptions of NoS and concluded that their inadequate views were primarily the result of inadequate curricula. The second line, which investigated the design and implementation of curricula (some using HPS) aimed at NoS conceptions, showed significant improvements in post-test scores but tended to ignore the central role of the teacher and their understanding of NoS. As more studies came to indicate the importance of teacher epistemology for influencing student learning this opened up the third line in the research.
to successfully implement HPS aspects into their instruction. The situation has only marginally improved since the time of Gallagher's (1991) paper, where he had identified the inadequate philosophy and history of science preparation which students receive from both their specialist undergraduate science courses in the academy and during teacher training in education faculties. Since then there have certainly been efforts undertaken in some countries (Australia, Canada, Denmark, Germany, Greece, Italy, some U.S states) to improve the HPS education of aspiring science teachers, although the success remains largely uneven and highly dependent upon individual researchers and teacher educators at given universities and faculties.

One suggestion of this Thesis is that a PoSE when shaping a teacher's pedagogical content knowledge—following Shulman's (1987) perspective—would seek to influence a science teacher's specialist content knowledge (CK) through HPS awareness and education (Chapter 4). From a hermeneutic perspective, this would mean to allow the horizon of a teacher's epistemology (or understanding of subject content) to expand through awareness of the need of nature-of-science insight and HPS integration as an essential component of their pedagogical content knowledge (PCK). (Discussed in Chapter 5).

Any discussion involving the nature of science (NoS) it will be admitted, is itself contested terrain among respective academic disciplines. This has certainly complicated the issues surrounding HPS inclusion and integration (Matthews, 2003; 1998; Leonard, 2003; Rudolph, 2000; Kelly et al., 1993). While a PoSE as I see it, would continue to support previous reform efforts towards HPS inclusion (e.g. Stinner et al., 2003; Monk and Osborne, 1996), it has the additional task of canvassing issues as debated in the philosophy, history and sociology of science disciplines in order to better ascertain the appropriate understanding of these issues for use in science learning, curriculum policy and HPS integration—showing both strengths and limitations for the classroom. This Thesis will contribute to this discussion by attempting to uncover aspects of the current debate in the philosophy of science concerning the nature of science, especially the realism/instrumentalism controversy as relevant for science education (Chapter 4).

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4 A glance at science teacher education textbooks does indicate the community recognizes the value of some PoS for teacher preparation. As examples, both the textbooks by Bybee et al. (2008; US) and Ebenezr and Haggerty (1998; CA) have one chapter devoted to philosophy of science, mentioning the philosophies of Bacon, Popper, and Kuhn explicitly. Summers (1982) was among those who explicitly addressed the need for PoS for science teacher preparation.
There still remains the question about the much-debated "disunity" of the sciences (Galison & Stump, 1996), also possibly indicated by the current fragmentation of philosophy of science into various new sub-discipline specialties (e.g., philosophy of biology, philosophy of chemistry, etc.). If one accepts the claim that there cannot exist any one "philosophy of science" (although there certainly exists an academic journal by that name) any more than a common language of science can be said to exist, but rather a multiple, then similarly the question arises if not a multiplicity of philosophies of science education may need to be considered and separately developed. Without wanting to address the complexity of the disunity debate, I am sympathetic to the gist of the argument, and that developing "philosophies of science education" may indeed be a possible (or even probable) future evolution of the general idea I have here initially suggested. On the other hand, a philosophy of science education may be only marginally affected by sub-specializations in the philosophy of science. While a teacher's content knowledge (CK) in chemistry, say, may need to be better informed by developments in the philosophy of chemistry—and one crucial component of PoSE would involve stressing this—nevertheless a PoSE is more concerned with how such CK can be made to fit with the requirements of an educational metatheory and its concern with the cognitive-emotive development of the learner, with respect to this subject matter. In other words, a teacher's CK and the curriculum are not at the forefront for learning science (although they are invaluable dimensions), as is commonly done. Rather, they are evaluated in light of philosophy of education and the learner's age-developmental mind-frame as befits what it means to educate a person in the sciences, and hence shifts the focus to the nature of a teacher's pedagogical content knowledge (PCK) and educational philosophy.

1.3. The Relation to Philosophy of Education

Thus far a discussion with respect to philosophy and philosophy of science as related to PoSE has been presented. With the aforementioned opinion that part of the responsibility of PoSE includes both the requirements to: i) enrich a teacher's pedagogical content knowledge (PCK) and ii) reveal educational philosophies and worldviews behind science educational approaches and curricula, we have now arrived at the subject of philosophy of education. One is amazed to discover however, that this
academic field has tended to be little referenced, if not almost entirely ignored, not only by science teachers in particular, but the science education research field in general. Here exists a landscape that has been barely explored. A possible exception is the original significance attached to this field by some authors within the revived History and Philosophy of Science (HPS) reform movement in the early 1990s (Matthews, 1994, Siegel, 1989), although that movement too, appears lately (last 15 years) to have lost sight of its merits (Matthews, 2009; personal communication). Other than the seminal authority of John Dewey (above all in North America), whose recurring influence has ebbed and flowed in time from the 1920s onwards, it can readily be admitted no other philosopher has since managed to significantly shape the science educational endeavor (DeBoer, 1991). One major feature of this Thesis will be an appraisal of Dewey’s philosophy of education, chiefly his conception of language in light of the “interpretive turn” (Chapter 5).

The almost complete neglect of philosophy of education in science education is evidenced in Fensham’s encapsulating book Defining an Identity (2004, p.54), by the sole entry of this subject matter on one page, which also cites Dewey. This is a truly remarkable finding, for this book traces the evolution of the international science education community seen as a research field from its origins and collects the insights obtained from the conversations of 76 prominent researchers in 16 countries active from the 1960s to the present. One finds that at most Dewey, and occasionally the philosopher Toulmin, rate any mention. In marked contrast, the book bears ample evidence of the much more pervasive influence of other disciplines, especially psychologists (Piaget, Ausubel, Bruner, and Vygotsky) and some philosophers of science (above all Thomas Kuhn) on the thinking and research of science educators as cited by the researchers themselves. Fensham in fact suggests that it is the “dominance of psychological thinking in the area” which attests to why Dewey is not cited more frequently among respondents in the USA. Here the other valuable purpose of PoSE becomes immediately obvious, to ascertain the legitimacy or scope of either borrowed ideas or transferred theories from “outside” disciplines into the educational field.

Most importantly, the question finally needs to be addressed whether the traditional (and ongoing) neglect of philosophy of education has not resulted in a number
of unforeseen debilitating consequences for science education, being preoccupied with borrowing ideas almost exclusively from psychology, philosophy of science and, lately, ethno-methodology and language theory. This Thesis argues there have been such effects with respect to the divisive historical project of defining goals, including “scientific literacy”, and further attested to by the transport of problematical psychological ideas from (just naming two) behaviourism and Piagetian theory to science learning in the past (Erickson, 1998; Matthews, 1994)—although the latter is true of learning for education in general (Egan, 2002, 1983; Thomas, 1997). The value and relevance of empirical educational research itself (EER) for improving teaching and learning, although long assumed, has recently come to be seriously questioned (Hyslop-Margison and Naseem, 2007; Phillips, 2007, 2005; Egan, 2005). Moving along this line, Slezak (2007) has even come to question the relevance of cognitive science for science education (a new science education research field) that several researchers are looking at for promising results to help guide instruction and learning. In light of these important developments, this Thesis asks if a partial shift in research direction towards philosophy of education and a reorientation of thinking is required for both science teacher training and science education as a field of research (Chapter 2).

In one sense this neglect is rather bizarre because science education is above all about education, with natural focus on the science specialty, while philosophy and education have roots that are intertwined in history long past, convincingly traceable back to Plato (Republic). Every major philosopher in the Western tradition from Plato (in Ancient Greece) to Kant (in the European Enlightenment) to Dewey (in modern industrial America)—or Confucius (classical China) in the Eastern one—have proposed educational projects of some kind. As Amelie Rorty correctly states (1998, p.1): “Philosophers have always intended to transform the way we think and see, act and interact; they have always taken themselves to be the ultimate educators of mankind” Understood in this way, Dewey was on the mark when he famously phrased the view that the definition of philosophy is “the theory of education in its most general phases” (1916, p. 331)—although I doubt most professional philosophers would construe it as such. In fact, the Enlightenment “project of modernity” (Habermas, 1987)—first begun in the 17th century—was expressly formulated as an educational project, and which saw in the new
science of the day an instrument for personal and socio-political liberation (Gay, 1969). It is of course in full awareness of this intellectual and cultural background that postmodernists like Lyotard would outright dismiss the “grand narrative” of this project with its associated role and image of science, including those science educators convinced by his critique (Schulz, 2007; Loving, 1997). Looking much further back in time (again at the Metaphysics), Aristotle identifies the man of knowledge—one who has attained expertise via techné or theoría—as the one who is plainly able to teach what he has learned, and as such draws one distinguishing feature of the philosopher. To be a philosopher was to be a teacher. Conversely, to be a teacher implies one must do philosophy (of one form or other). Science educators seen in this light, are inescapably located within a venerable philosophical tradition, along with the newer scientific one which they usually and exclusively tend to associate themselves with—though, here too, not fully aware of the latter’s cultural roots and significance.

Why they do not associate themselves just as intimately with philosophy, or at any rate with philosophy of education, is a fascinating question, one we really cannot pursue here. Yet it almost certainly has a lot to do with factors such as: the prestige of science in society, how specialized knowledge is structured, how their own university science education proceeded and, finally, how they were trained as educational professionals. What is called “Foundations in education” courses, which usually include studies in the history and philosophy of education, are often optional for pre-service science teachers, depending upon the prerequisites of their attending institutions. (Hirst complains that in some countries such as the United Kingdom there are now moves afoot to de-list such courses for teacher training in general; 2008). If an examination of the preparation of science education researchers is any indication of the kind of academic preparation science teachers themselves receive (before they become researchers), then a second look at Fensham’s Identity book as commented on by Matthews (2009b, p.23) is revealing. He notes that “the interviews reveal that the overwhelming educational pattern for current researchers is: first an undergraduate science degree, followed by school teaching, then a doctoral degree in science education” (citing Fensham, 2004, p.164). As Matthews’ concludes, unfortunately “most have no rigorous undergraduate training in psychology, sociology, history or philosophy”. Fensham himself comments (p.22) that at
best, "as part of their preparation for the development tasks, these teachers had opportunities to read and reflect on materials for science teaching in schools and education systems that were different from their own limited experience of science teaching." Matthews observes this may be the significant reason why the science education research literature "is dominated by psychological, largely learning theory, concerns" (ibid). Others have also cited the domination of psychology and conceptual change research (Hodson, 2003; Gunstone and White, 2000). It certainly appears as if the inadequate teacher training in philosophy of education is mirrored by the previously discussed case with respect to philosophy and history of science.

Now some may think that being relatively new sub-disciplines, philosophy of education and philosophy of science have not yet shown their immediate worth for teacher preparation and school instruction. This view could mean that because they are recent their relevance has not yet become apparent, or, being recent they have not (yet) been accorded the worth they deserve—possibly due to their own faults, either because their relevance for teacher "preparation" is tough to establish, or because unresolved in-house disputes and theories are shown of little value (e.g. positivism). Either way, such views are spurious because, first of all, both sub-disciplines are not as "new" as some may think, and to dismiss a discipline either because some conceptions have been found wanting or been superceded, or because expected results for "skills" and training purposes are not clearly identifiable, is to be extremely shortsighted, to say the least (to say nothing about what narrow notions such views entertain concerning the nature of professional preparation for teaching and curriculum analysis).

Philosophy of education, depending upon the given nation and its educational traditions, can be viewed as a relatively new discipline or not. As Hirst (2003, p. xv) points out, "philosophical inquiry into educational questions" is more established in the US, Germany and Scandinavia, whereas in the UK philosophy of education as a discipline first came into its own in the 1960s. It was dominated by analytic philosophy and accounts of schooling, although in ethics Kantianism was the major influence. In the USA, the American Philosophy of Education Society had already been founded earlier in 1941, along with the Deweyan journal Educational Theory in 1951. On the Continent in Northern Europe, the ideas of Kant, Herder, Herbart and others had created the influential
\textit{Bildung} paradigm in the 19th century, which had itself begun to clash with the ‘Critical Theory’ of the Frankfurt school by the 1960s (Blake \textit{et al.}, 2003). I mention this here for several reasons: from previous comments on the developments of science education it is clear that for the English-speaking nations, the USA was in the forefront of the establishment of both disciplines which have developed in tandem—simultaneously but separately. Yet one would think that because of this pedigree, and in some cases of clearly overlapping interests (as shown in the case of Dewey), that science education would be more cognizant, and science teacher training more reflective, of their common roots. Sadly, science educators seem in general to suffer amnesia on both counts, for if it is true that “philosophy of education is sometimes, and justly, accused of proceeding as if it had little or no past” (Blake \textit{et al.}, 2003, p. 1), then this certainly rings true of science education. This complaint is well attested by DeBoer in his insightful \textit{History of Ideas in Science Education} (Preface, 1991). The call for PoSE is not only to raise awareness of this forgotten earlier period, but to identify the need to create a sub-discipline within educational studies that, although new, nonetheless has substantial historical roots going back into the science-educational but especially the philosophical-educational past. (Chapter 2).

It is my contention that teachers as well as researchers when becoming more conversant with the ideas and disputes in the philosophy of education will help them (at minimum) gain insight and perhaps (at maximum) resolve problems related to issues of common interest (the nature of aims; educational theory; multiculturalism; education for citizenship; ideology and curriculum; language and learning, etc). Here Amélie Rorty’s list of questions serves to illustrate my case, which I have \textit{transposed} onto science education: “what are the directions and limits of public [science] education in a liberal pluralist society? … Should the quality of [science] education be supervised by national standards and tests? Should public [science education] undertake moral education? [as to some extent those arguing for Socio-Scientific Issues (SSI) reform insist (Zeidler \textit{et al.}, 2005)]. … What are the proper aims of [science education]? (preserving the harmony of civic life? Individual salvation? Artistic creativity? Scientific progress? Empowering individuals to choose wisely? Preparing citizens to enter a productive labor force?) Who should bear the primary responsibility for formulating [science] educational policy?
(Philosophers, ..., rulers, a scientific elite [e.g. academic scientists], psychologists, parents, or local councils?) [see Fensham, 2002, DeBoer, 2000, Jenkins, 1994, for responses to such questions by science educators]. Who should be educated [in science]? [Recall the ongoing historical dispute between the ‘science-for-the-few’ and ‘science-for-all’ perspectives on curriculum and goals]. How does the structure of [scientific] knowledge affect the structure and sequence of learning? ... What interests should guide the choice of [science] curriculum?” (Rorty, 1998, pp.1-2).

It is quite clear that common questions and concerns exist and one would have expected more cross-disciplinary discourse than has heretofore existed. I cannot hope to address all of these in the Thesis here presented, rather my emphasis is to show common alliances and the need for dialogue across disciplinary boundaries and to sketch out the nature of the work a PoSE has before it. That said, individual questions will indeed be addressed, in particular the questions of direction and aims of science education, as well as the last two questions regarding the problem of the structure of knowledge and driving interest groups (Chapter 2).

As indicated however, some of these questions have been debated before, though solely within the confines of science educational research circles, and rarely are they addressed at the teacher education level. To support this latter claim I again cite the common textbook for pre-service teachers by Bybee et al. (2008/1967), which, granted, does address the question of science educational goals and history, but strictly without reference to the wider discussion and debates as found in philosophy of education. Another example is Llewellyn’s (2005) popular book, endorsed by the influential US National Science Teachers’ Association (NSTA), on science teaching by inquiry. It gives the impression that science education as an inquiry approach is basically constructivism and learning theory writ large, which essentially began with Dewey. There is little awareness of other historical developments or even notice that the problems raised have wider philosophical-educational pedigree and significance. This book, as is common, defers to psychology (esp. Piaget and Vygotsky) and typically equates “educational theory” with constructivism. Worse, scientific “inquiry” as a complex methodology linked with crucial debates in philosophy of science is completely ignored (which at least Bybee et al., have the wit to briefly enunciate in their textbook).
It is suggested here that another important role for PoSE is the need to not only locate hidden philosophies with their educational theories (or “meta”-theories, e.g. Plato; Rousseau; Whitehead; critical pedagogy) but to actively create such theories—or another possibility, to show the relevance of those educational metatheories which exist as proposed in philosophy of education or curriculum studies, to illustrate their worth for improving science teaching and learning (Waks, 2008; Scott, 2008; Walker, 2003; Egan, 1997). To that end this Thesis will describe and examine Kieran Egan’s cultural-linguistic metatheory, including a brief comparison with the Bildung-centred Didaktik tradition of Central and Northern Europe. The purpose will be to expound upon its relevance for solving common problems not only engendered by student learning of science but equally engendered by unresolved internal disputes with respect to science education goals, especially scientific literacy (Chapter 3).

1.4. The Nature of Philosophy of Science Education: Scope and Possibilities

With the previous discussion in mind and the various aforementioned italicized suggestions, we now come to the topic of summarizing the scope and possibilities of a PoSE as well as the direction and organization of this Thesis.

It is my contention that there is a need to develop an in-house “philosophy” of and for science education itself. This idea on the surface may not appear completely new, however. One could possibly argue that vestiges of the idea have appeared in Dewey, according to Shamos’ (1995) interpretation. Anderson (1992), when examining science education reform in a more comprehensive fashion, has repeated the worth of including “philosophical perspectives” as one vital dimension (in a multiple perspective analysis) when discussing how to make curricular reforms more successful. Nevertheless, keeping such indistinct suggestions in mind, I believe the call for such a specific philosophic sub-discipline for science education is indeed novel. Here there also exist previous cases for the call of new sub-disciplines. It may well be that the developments in the past of the creation of separate academic sub-disciplines within philosophy, such as the two just mentioned, philosophy of science and of education (also of religion), have arisen for similar reasons. And there are even excellent examples of very recent precedents for the creation of such disciplines, such as the philosophy of chemistry (about 20 years old;
McIntyre, 2007) and *philosophy of mathematics education* (see Ernest, 1991). The creation of any new discipline will only be acknowledged in so far as a group of scholars working on certain issues and problems find that their research interests can no longer be accommodated and foresee the need to move in new directions of inquiry. My view concurs with Scerri and McIntyre who defended their new discipline of "philosophy of chemistry" with the following words:

> Of course, there are always some who wish to drag their feet; to deny the legitimacy of the interests of those who first make their way into a new discipline. Yet ultimately, if the discipline has enough people who are interested in it, and who are willing to chip away at the parochialism of those who would deny it, a new field of inquiry gradually emerges (1997, p.211).

I foresee PoSE could serve as an academic forum where fundamental goals, criteria for content selection, and critiques of epistemologies, research methods, learning theories and instructional strategies, can be debated, along with the focus on developing in-house educational metatheories—especially how such theories can inform practice—can be nurtured. Also it should help clarify the relationship between educational theories and philosophy itself, which has its own concerns, as Hirst (1966) first noted.

The purpose of this Thesis is to both *make the call* and to *justify* it. It makes the case in more detail than could be made in a recent (June, 2009) professional public "call" in front of an international audience of scholars at the 10th *International History, Philosophy and Science Teaching* group (IHPST) at the University of Notre Dame, in South Bend, Indiana. This symposium was called in response to the publication of my two papers in the journal *Science & Education* (Volume 18, April, 2009, pp. 225-273) on the subject of science education reforms and Egan's metatheory, the content of which is largely reproduced in Chapters 2 and 3, with some additions. These two papers (and as elaborated in the two chapters), sought to justify why a PoSE is required. They will be summarized in a moment. What they did not do sufficiently is articulate the *scope* and *possibilities* of what the nature of PoSE might entail. This I wish to do now.

- The *scope* of its field of inquiry and analysis of central issues can be organized around at least *nine* topics or *problem-sets*:
(i) Goals of science education (& science literacy);
(ii) Development/analysis of educational meta-theories for science education;
(iii) Nature of science (NoS) as suitable for science education;
(iv) Nature of science learning (NoSL, and critique of learning theories);
(v) Nature of science teaching and assessment;
(vi) Nature of ideology and interest in curriculum; criteria for content selection;
(vii) Nature of language (NoL) in curriculum, instruction and learning;
(viii) Relation of science literacy and goals to socio-technology issues education;
(ix) Relation of science and science education to worldviews and cultures.

This is not meant to serve as an exhaustive list, and it is to recognize that some topics have already found an audience for discussion. The topic regarding item (vii) is a relatively new field of science education research (Fensham, 2004) but is found wanting for present lack of comprehensive philosophical treatment. My chapter #5 discussing the nature of language by contrasting Dewey and Gadamer’s conceptions, is meant as a contribution in this direction, linked to the previous input of Eger (1992; philosophical hermeneutics) and Lemke (1990; semiotics).

Given the above list, it is recognized however, that no such single academic platform currently exists to bring the topics into better focus, for enhanced dialogue and more comprehensive analysis, although the listed topics and debates have appeared sporadically over time and for different reasons, and some are scattered across different research journals and handbooks. And the items on the list aim to acknowledge the internal conflicts within the field. Hence, I do not mean to imply that others have not already been engaged in aspects of what is here described as a philosophy of science education. But because of the ongoing sub-specialization within science education I fear

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the consideration requisite to such concerns and the need for a broader, integrated inquiry field is, and continues to be, lost sight of. Fensham (2004; 2000) and Jenkins (2001, 2000) have dropped tantalizing hints in this direction. Certainly what Kyle et al. (1992) have suggested would move within the orbit of such a sub-discipline (to delineate the field of research inquiry itself), as would an analysis of various “research programmes” of learning theories (item (iv): Anderson, 2007; Erickson, 2000).

- The possibilities for reform and what a reorientation might imply:
I currently see three areas for potential reform:

1) Science education as a field of research (Jenkins, 2001; Kyle et al., 1992)
2) Science teacher education and curriculum (Abell, 2007; Fensham, 2004)
3) Science education as a discipline; defining its identity (Fensham, 2004)

With respect to (1): the suggestion is that at the academic level a new research direction or area of inquiry should be undertaken in science education. This may involve the creation of a new journal, possibly called “Philosophy of Science Education”.

Jenkins (2001) has complained that the field of science education research has been too narrowly construed (in part as a critique directed at the two earlier Handbooks Fraser and Tobin, 1998; Gabel, 1994): it has been overly preoccupied with teaching and learning as practice, and thereto, suffers from “an over-technical and -instrumental approach” (p. 11), at the expense of other perspectives, such as “the long-standing neglect of historical studies of science education, and more widely, of research not related directly to the teaching and/or learning of science” (p. 12). This should certainly encompass explicit educational philosophical reflection on educational theory, which even he fails to mention. Along with the three predominant kinds of research in science education today—quantitative, qualitative-interpretive, and critical-emancipatory (Fensham, 2002; Kyle et al., 1992)—I would argue for the pressing need of a fourth, philosophical (or philosophic-historical).
With respect to (2): it remains to be clarified how a PoSE would impact the understanding of teacher education programs, especially its relation to the on-going research on Pedagogical Content Knowledge (PCK) and its elaboration (Abell, 2007). Fensham (2004) has recently argued for an alignment of the Bildung tradition and PCK. He sees in the Bildung tradition a critical element for content selection and curriculum analysis that is missing in the typical aphilosophical Content Knowledge (CK)-focused science curricula of English-speaking nations. What he fails to recognize however, is that the Bildung tradition itself represents an example of an educational meta-theory, on par with Egan’s cultural-linguistic metatheory (1997). An important task of PoSE would be a critical comparison of these metatheories, their relation to PCK and their impact on science teacher education (see above “Scope”, item ii). A brief discussion is undertaken at the start of Ch.3 (see especially Figure #1).

With respect to (3): My suggestion is that an educational meta-theory could ideally contribute to grounding science education as an autonomous discipline by helping distance it from its historical dependence on psychological metatheories and economic or socializing ideologies. It would contribute to further defining its identity (Fensham, 2003). Although this claim is not addressed by Fensham and the researchers he had canvassed, it is mentioned at points in Ch.2.

It stands to reason one could accept points #1 and #2 above as belonging to the proper inquiry field of PoSE, and hence argue for its inauguration, and not be committed to point #3. That is, one need not hold that science education is either a discipline nor that it requires meta-theories characteristic to it—although I will argue the opposite case. Then again, as I understand what belongs to the essence of philosophy as mentioned above, it means a project which invokes not only analysis but also the creation of new

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6 Gunstone and White (2000) have earlier sought to make the case for science education as a discipline but they linked it with the criterion that as a research field it was required to show progress. By concentrating strictly on research related to students' content learning and alternative conceptions, they answered in the positive by identifying two key factors which indicated progress: changes in research styles over time and the discovery of several learning principles. They also suggest science education should be aligned with the social sciences and as such could not aspire to the rigor of the natural sciences, which can show a development in their investigative processes from general principles to “laws”. Science education, they argue, could at best aspire to the discovery of principles.
ways of seeing and doing education. In other words, the active development of metatheories appropriate for the sub-discipline of science education.

1.5: Overview of the Thesis and its Argument

This brings us to the present investigation and the organization of the Thesis. My personal route of discovering the need of a PoSE arose from my own experiences working both in science classrooms and with pre-service science teachers, and which are generally tied to the widely-recognized issue of the problematic (or unsuccessful) nature of implementing effective reforms in science education. What is true of my experience—that one’s own philosophizing usually emerges out from the problems of the socio-educational environment one is immersed in and concerned about—happens to correspond with Dewey’s insight “that philosophical problems arise because of widespread and widely felt difficulties in social practice” (1916, p.328). Or perhaps put simply, my discovery resulted from “a sense of wonder”, as Aristotle had identified the origin of philosophy. It was the inability of my secondary students to generally improve their grades in their junior and senior classes, regardless of my pains taken at direct instruction, tutoring, modified group and inquiry activities, that brought me to re-examine and question my entire pedagogical approach.

My junior science students were interested but not overly enthused with the predominant curricular academic diet, and showed little improved comprehension at year end, time and again. I was stunned, for I believed my experience with over 10 years of classroom teaching (including international experience), my enthusiasm, the concern I showed for their learning, my continued professional interest in reading science literature and following and incorporating the latest scientific findings, would have borne better fruit for my students. It was not that my senior students did not perform well on state-mandated, standardized final exams; on the contrary, they did exceptionally well for the most part. This discovery was also a puzzlement. But what I continued to observe was a lack of deep understanding, with little comprehension of what science or physics was about and meant to them, how it had developed or could be used, and generally, little interest to pursue it further. At about this time of discouragement and bafflement, I became more critical of the academic science curriculum and sought out what I believed
to be more accurate historical portrayals of scientific development than had been commonly presented in textbooks I had been using. I also occasionally incorporated stories and philosophical aspects into my science teaching, especially in my senior physics classes with special focus on the Copernican revolution. This became an extension to the regular dry and difficult material on gravity, Kepler's and Newton's laws. (I slowly discovered glaring historical errors and embarrassing simplifications of theories, "method" and scientific progress; for example, how atomism and key experiments were discussed in chemistry textbooks). But even while some students became genuinely enthused, others questioned the relevance of HPS for their science courses with their pre-set exams directly tied to college placement. Most students in senior classes, not surprisingly, had developed a very instrumental attitude to learning and content of courses. Yet through these experiences, I was gradually led to science education research, the large body of literature on misconceptions, constructivism and the HPS reform movement. This trajectory, looked at in hindsight, was probably inevitable.

So, it can rightly be said that I did not so much "discover" philosophy of science education as it discovered me. To make the case for a PoSE is to imply that a "wider dimension" of science education reform has until now been missing. It is then not surprising that Chapter 2 is concerned with why the solutions offered have so far been proven inadequate. Why have the problems not been satisfactorily resolved? How can one overcome the deadlock in the historically identified, essential goals of science education, which seem to be at cross-purposes (Bybee and DeBoer, 1994)? Is there a successful resolution that the community could accept concerning the contentious and divergent meanings of science literacy (Roberts, 2007)? Thereto, why is learning of science concepts so difficult, why is understanding so elusive, and are there significantly better ways of learning not fully considered despite several decades of research (Egan, 1997)? To that end, the research question to be adopted is:

Research Question:

What can a philosophy of science education contribute towards improving conceptual understanding of science and science education as a discipline?
This broad question will be broken down into specific questions that are addressed in the chapters which follow:

1. How can a philosophy of science education contribute to the reform of science education goals and the conception of literacy? (Ch.2)
2. What does it mean to be educated in science? (Ch.2)
3. What does conceptual understanding entail? (Ch.2/3)
4. How does one best come to learn science? (Ch.2/3)
5. What is a “metatheory” of education? (Ch.2)
6. Why does science education require a metatheory? (Ch.2)
7. What is Kieran Egan’s metatheory about and how can it improve science education? (Ch.3)
8. What is the contribution of a philosophy of science education to the nature of science (NoS) discussion? (Ch.4)
9. What is the contribution of a philosophy of science education to the nature of language (NoL) discussion in science education? (Ch.5)

From this list of questions one clearly notices that I hope to play my part in analyzing and contributing solutions to those problem-sets identified earlier under the “Scope” for PoSE inquiry. Especially, items (i); (ii); (iii); (iv); (vi) and (vii). It should be emphasized that some of these questions address new topics, while others venture onto well-trodden ground (question #8) or familiar territory (question #9) but from a PoSE perspective. It is further to be understood that any solutions suggested and ideas proposed are tentative and meant to contribute to continued scholarly discussion and research.

The Argumentation of the Thesis

To re-think science education as an educational endeavor: an analysis of key learning issues in the physical sciences; the re-examination of its fundamental goals—especially science literacy—the relevance and yet problematic status of epistemology and nature of science (NoS) for curriculum and teachers; the need to shift its research emphasis towards philosophy of education and educational theory; the value of
considering Egan's *metatheory*, and finally the need to scrutinize the role and *nature of language* (NoL) in Dewey and science education from a Gadamerian-hermeneutic perspective. It is argued that for educators the *nature of science learning* (NoSL) must be informed by a critical consideration of educational theory, the nature of science (NoS) and the nature of language (NoL). These themes are themselves not new, of course, but I believe what is original is the way they are treated and brought together.

The *second chapter* has several aspects structured around the evidence of the widely recognized issue of the problematic (or unsuccessful) nature of implementing effective reforms in science education. The Thesis takes the perspective that the problem is to be located at the nexus of at least three key factors: (i) competing school-based "paradigms" with their own largely exclusivist conceptions of scientific literacy, and tied to competing interest groups; (ii) the prevalent disregard of philosophy of education, in conjunction with (iii), the ongoing neglect of generating discipline-specific educational theories (not restricted to learning theories, and which could help clarify curriculum and goals). Common "crisis-talk" is seen to mask competing paradigms and interests. Hence it is suggested that a turn towards more philosophical-based reflection and educational theory in the discipline is required, with the proposal that a metatheory may offer an answer to the dilemmas we face. The nature of metatheories is then discussed and clarified. Finally, more reasons are provided why science education requires a metatheory of education, being linked with the options left to the community in the *literacy debate*.

The *third chapter* then concentrates on presenting and describing Egan’s metatheory and providing some examples how it can contribute in concrete ways to improving science education. As a preliminary to this examination, a comparison is made between the educational systems of the Anglo-American “Curriculum” tradition and the German-Norse *Bildung* tradition, since the latter is characterized by use of a renowned metatheory. Other parallels are also drawn, in particular the role of a “philosophy of science education” as linked to *Didaktik*-analysis and Shulman’s pedagogical content knowledge (PCK). Once Egan’s metatheory has been explicated in some detail, some links are drawn to other researchers who have emphasized the importance of using narrative and the history of science for improving instruction and learning. On the other
hand, a metatheory of education only addresses the issue of the nature of science learning (NoSL) and leaves the question of the nature of subject content largely aside.

The fourth chapter turns to the key issue of how to address the need to problematize the content knowledge (CK) of science disciplinary subjects, especially the problem of the image of science as it is found in epistemologies of curriculum and textbooks, which a general metatheory of education must draw upon and is intended to educate students about. The HPS reform movement is referenced and how it is attempting to address these epistemological issues, including the issue of improved nature of science (NoS) understanding and integration to help reshape the CK base. Problems associated with NoS are looked at, as well as a case study examining the realism/instrumentalism problem in recent PoS debates. It is recognized that the problem of the nature-of-language cannot ultimately be ignored and that a hermeneutic perspective on language and a move “beyond epistemology” may also contribute to improved learning.

The fifth and final chapter thus turns to the nature of language (NoL). It briefly summarizes the literature on language as a new research field in science education, and discusses the “interpretive turn” in philosophy of science and language. It acknowledges that the so-called turn “beyond epistemology” is contentious. Nonetheless the Thesis suggests that a focus on Gadamer’s philosophical hermeneutics and his conception of language can offer profound insights into the nature of learning that has been largely ignored in science education research. In particular, a significant portion of the chapter is dedicated to a nature-of-language case study involving a critical examination of Gadamer’s and Dewey’s notion of language. It is argued that Dewey’s “symbol and tool” view continues to dominate science education to its detriment. The shift from epistemology to ontology is discussed and shortcomings also in a Vygotskian “tool view” of language are identified. Some shortcomings in Egan’s metatheory are also discussed. These shortcomings need to be considered when looking at student learning problems and suggest areas for continuing research.

Other Final Considerations:

The topic of the case for a philosophy of science education necessarily addresses and must include dimensions of three fields of inquiry, which themselves embrace their
own venerable historical traditions and specific contemporary research programmes: philosophy, science and education. It is understood that an attempt to consider each to the degree of depth and completeness they require would be an undertaking not achievable in the kind of work here suggested. This much must be acknowledged, and hence one must at the outset set limits as to the direction and scope of the inquiry. Regarding philosophy, the scope will now be narrowed to aspects of philosophy of science (especially epistemology) and philosophy of education (especially educational theory) as they bear on the arguments and intention of the Thesis. Here one should quickly add, however, neither will it be possible to fully explore the significance of these two sub-disciplines—those albeit not as old and well-established as the aforementioned three—which certainly has substantial bearing on the present project. Thereto, some dalliance with respect to language theory and philosophical hermeneutics will be included. Regarding science, the focus will be primarily on physics (including its historical development), to a lesser extent on chemistry, but also with some reference to geology. Finally, regarding education, the primary concern will be the literature and research programmes pertaining to science education (including referencing Physics Education Research (PER), and Chemistry Education Research (CER)), together with a discussion of metatheories, of curriculum, learning theories and conceptual change literature, and the relatively recent social-cultural research tradition. As well, there will be a concern to address what sort of ramification a “philosophy of science education” has for science teacher education. This will include examining Shulman’s conception of Pedagogical Content Knowledge (PCK) and the German-Norse educational tradition of Bildung. The Dissertation is clearly a work of interdisciplinary scope, enriched and encumbered by the character that such work entails, which will judiciously draw on the fields of inquiry mentioned in order attempt to address not only some pressing contemporary problems of science education reform but equally to make the wider case for the creation and establishment of a new sub-field of inquiry of science education.
CHAPTER TWO: Science Education Reform and the Need for Philosophy of
Science Education and Educational Theory

“History teaching still turns a blind eye towards science, the most exciting and
noble of human ventures, and science and mathematics teaching is disfigured by
the customary authoritarian presentation. Thus presented, knowledge appears in
the form of infallible systems hinging on conceptual frameworks not subject to
discussion. The problem-situational background is never stated and is sometimes
difficult to trace. Scientific education—atomized according to separate
techniques—has degenerated into scientific training. No wonder that it dismays
critical minds.”

—Imre Lakatos, philosopher of science

2.1. Surveying the Issues

This chapter is concerned with how science education reform can be made more effective
but takes a very different perspective from many present and previous deliberations in the
extensive literature on this topic (Sunal et al., 2004; Hodson, 2003; Fensham, 2002; Roth
& Desautel, 2002; Donnelly & Jenkins, 2001; Hurd, 2000, 1994; Jenkins, 2003, 2000,
1992; DeBoer, 2000; Solomon, 1999; Millar & Osborne, 1998; Lederman, 1998; Bybee
& Ben-Zvi, 1998; Claxton, 1997; Millar, 1997; NRC, 1996; Yager, 1996; Shamos, 1995;
Matthews, 1994; Bybee & DeBoer, 1994; AAAS, 1993; Shymansky & Kyle, 1992;
Duschl, 1990). It seeks to harness insights from research in particular fields (social
constructivism, cultural-linguistics and philosophy of education) to argue that science
education both as academic discipline and practice requires foremost an overarching
theory of education for and about science comprehension. Although science education
research continues to be heavily influenced not only by ideas but especially by theories
coming from outside the discipline itself (primarily from the fields of psychology,
philosophy and sociology of science, socio-linguistics and cognitive science), little
attention has been given to developing in-house specific educational theories which
could better attend to the needs of science teaching, learning and curriculum unique to it,
and which (as an educational sub-discipline) it more properly shares with others in
educational studies. Such insights though as can be gleaned from these other academic
fields which can throw light on the complexity of education are naturally to be
welcomed, but the point here is that due to the poverty of educational theorizing within
much of science education such imported theories tend to overshadow and mask the need
to develop in-house theories which could help resolve conflicts internally generated—those for example, which revolve around questions of goals, values, content selection, learning and instruction.\(^7\)

Moreover, not only do these external disciplinary theories usually have various built-in constraints of their own (only occasionally acknowledged), they serve at best to illuminate only partial aspects of educational concerns—for example, offering ideas about development, motivation, memory, learning, and others—and they tend to offer these from perspectives which can have little in common with what either the practitioner or educational theorist is ultimately concerned with, or worse, their application may do outright damage to education (Slezak, 2007; Egan, 2005a; Thomas, 1997).\(^8\) These points cannot be emphasized enough. As will be argued, some of these ideas and solutions embedded as they are within their own theoretical framework (for example, the Piagetian stage theory of development) could very well be in conflict with an alternative, fully developed educational theory (Hirst, 1966). In any event, although they may be able to address some aspects and issues, they certainly cannot address the more fundamental ones pertaining to the values, goals and teaching of science exclusive to it, such as the ongoing disputes over the meaning and assessment of scientific literacy, even the recent critical questioning if such a key aim is either reasonable or attainable (DeBoer, 2000; Shamos, 1995). My view concurs with Donnelly (2004, p.778) that “science curriculum reform [should] be seen as a self-contained transformation, motivated by an independent vision of the aims and purposes of science education.”

Therefore the call to re-shift the focus of science education, especially to address those within the community (philosophers, curriculum theorists, learning theorists, practitioners, etc.) concerned with the broader questions of science education as an educational endeavor including the aims, ideas and issues respective to it (goals, conceptions of development and learning, curriculum reform). Hence, the renewed call

\(^7\) One can certainly make a good case that the ensuing debate over constructivism, for example, which has preoccupied the community for over two decades, and which some promoters at the onset had described as a “new paradigm” for the discipline, can now be traced to initial unreflective considerations of the various philosophical underpinnings of its many forms (Scerri, 2003; Phillips, 2000; Geelen, 1997).

\(^8\) For example, the concept of learning as defined by computer-based artificial intelligence models in cognitive psychology could be necessarily at odds with what educationalists mean by “learning”. Some still recall the deleterious effects on education resulting from importing ideas of behaviorism (Matthews, 1994). Slezak (2007) has also come to question the relevance of cognitive science claims for science education.
for a return to some educational philosophical groundwork, a call certainly heard before
(Matthews, 1994; Siegel, 1989; Scheffler, 1970), but this time with the heed to develop
an explicit *philosophy of science education*. Not generally since Dewey (1945; 1916) has
such a particular deemed emphasis been brought to bear in science education—something
those within the larger community have basically lost sight of (an exception is Roberts
and Russell; 1975)—and as is well known, whose image of science played a key role in
his overall educational philosophy, including applying its assumed scientific way of
thinking ("method") to enhance the reasoning skills of students and thereby hoping to
forward democracy in society. Such principles have now become the hallmark of
progressivism and they continue to influence science educational ideas today (Wong *et
al.*, 2001; Bybee and DeBoer, 1994), especially the STS reform movement and their
science literacy conception (Hurd, 2000; Yager, 1996), although the actual link to an
erlier educational philosophy is often overlooked or not clearly delineated (Rudolph,
2002; Shamos, 1995; DeBoer, 1991). My argument in effect is to turn the focus around:
*not* to expand the notion of science education, to be used as a cornerstone for an
educational philosophy in general (as Dewey had hoped to do), but rather to explore ideas
in education in so far as it is possible to develop an overarching *educational*
framework—or *metatheory*—and to bring this back into the fold of science education to
help guide and solve curricular and learning issues relevant to this field.

This is where I believe Kieran Egan’s ideas can be of immediate importance
(2005b, 2002, 1997; 1986). He affords us the ability to conceive of education in relatively
new, creative ways and with a rather different set of categories and vocabularies
("cognitive tools", "imagination", "narrative understanding") than those heretofore
commonly employed in educational discourse ("structure of the discipline", "knowledge
forms", "stages of development", "growth", "constructivism", "information processing",
"multiple intelligences", etc.). His cultural-linguistic theory of education (concerning
educational and not *psychological* development) will be introduced and elaborated as one
possible over-arching conception of education which can serve to guide curriculum
development and learning about science, especially since crucial narrative aspects of his
theory already coincide with current work by some HPS reformers (Metz *et al*., 2007;
Klassen, 2006; Stinner *et al*., 2003; Stinner, 1995). Furthermore, besides the obvious link
to the "narrative approach", which is receiving increased attention from several researchers (Norris et al., 2005; Millar and Osborne, 1998), there are conceptual and theoretical links to the growing body of work drawing on Vygotsky, cultural psychology and language studies which focus on discourse and the social-cultural nature of learning and development (Carlsen, 2007; Duit and Treagust, 1998; Sutton, 1998; Kozulin, 1998; Moll, 1990; Lemke, 1990).

Egan’s conception of an educated mind certainly aligns itself (in large measure and to various degrees) with those who have always sought to frame science education in terms of broader aims, such as cultural literacy (most recently Carson, 2001), or that it needs to be properly located within a global (Snively & MacKinnon, 1995), ‘humanizing’ or even ‘liberal education’ framework (Aikenhead, 2007; Donnelly, 2004; Carson, 1998; Shamos, 1995; Matthews, 1994)—and much less so to be confined either to narrow technical training (traditional curriculum) or understood primarily as means to serve civic and/or socio-political ends (the ‘socialization’ imperative; typically the STS movement but more recently “science education for socio-political action”; Hodson, 2003; Roth and Desautels, 2002; Jenkins, 2000; 1994). Granted, all three expansive goals (cultural-personal, technical-disciplinary, socio-utilitarian) have accompanied the history of science education for a century or so, each continues to have force and forceful spokespersons, and each has come to the fore for different reasons in the past (Bybee and DeBoer, 1994). As Mathews (1994, p.15) clarifies, these “curricular orientations” are not necessarily mutually exclusive: “Curricula that stress one, usually include something of the others. What is in contention between the views is the general orientation of the science program, and the goals that it seeks to achieve.” Most importantly, the connotation of “scientific literacy” has shifted accordingly (DeBoer, 2000).

Indeed, it is time to ask the essential questions once again: “what does it mean to be educated?” (Barrow and Woods, 1975/2006), and supplemental to this for our particular profession, “what does it mean to be educated in science (and in physics, in geology, etc.)?” This latter crucial question should be kept distinct from—though it often

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9 This would include the Bildung tradition which has influenced educational ideas and curriculum in Germany, Central Europe and Scandinavia (Sjoberg, 2003). Duit et al. (2007), writing in a recent review of physics education, have commented that the common notion of science literacy in the English-speaking nations is burdened with an overly instrumental conception and generally neglects to emphasize the importance of developing the individual personality, which is vital to the Bildung conception.
tends to be subsumed to—the question harbouring a social utilitarian criterion: “what do we educate people in science for?” Depending upon the stakeholders involved with science education (students, teachers, parents, business community, academic scientists, science education researchers, etc.) one expects very different kinds of answers to these questions, while science education history bears special witness to the array of answers provided to the dominating utility question in particular with respect to the science literacy debate (DeBoer, 2000; 1991).

What is normally done is to start with the utility question first, to look “outside” to the demands of either society or the professional science community and then proceed backwards to define goals and structure curricula according to the needs and diverse demands defined there. Egan offers us the choice of starting differently, from a potential autonomous and “inside” educationalist perspective (and subsuming the utility question). Although Egan himself is not considered in some circles to be a professional philosopher of education he nonetheless addresses issues pertinent to educational philosophy and seeks to help bridge the disciplinary gap between philosophy of education and genuine educational (curriculum) theory. Moreover, as an educational theorist he has long argued for the establishment of education as an autonomous discipline, for it to be better demarcated from other fields of study (especially psychology; 2005a; 1983), and his reasons here serve equally well to further the self-conception of science education as an independent sub-discipline (a noteworthy topic which can only be touched upon here). The questions to be asked, and the solutions sought, is whether his comprehensive educational theory (“metatheory” or “grand” theory) can contribute in significant ways not only to enhancing science learning (the narrower use), but also if it can help resolve at long last in some sort of definitive way (assuming many in the community would accept it) the enduring impasse in the self-conception of school science education due to its central goals being at cross-purposes (the wider use). These are questions addressing different audiences, the former focusing on teacher pedagogical knowledge and learners, the latter focusing on the wider research community with its evolving history and identity.

With these solutions in mind this chapter has been organized into five further sections and will be concerned with the important theme of developing a self-reliant
**philosophy of science education** for teachers and the research community, whereas the following chapter (Ch.3) will address Egan's theory directly. In the next (or second) section a succinct overview about the quandary of science educational reforms is presented to clarify the deadlock in the major goals, including reference to the lack of consensus concerning scientific literacy conceptions. These problems will lead us to ask, in the third section, whether or not a turn towards more philosophical-based reflection and educational theory in the discipline is required, with the proposal that, among others, a metatheory may offer an answer to the dilemmas we face. The fourth section will then address the question: "what is a meta-theory?" The fifth and final section will ask: "why does science education need one?", notably addressing the options resulting from the "scientific literacy" debate and dilemma.

### 2.2. Overview of Science Education Reforms: A Recycling of Competing Ideas?

Around the world, science education is in a period of intense self-reflection and self-criticism as it moves into the 21st century. For a while now some authors have even described the situation as one of "crisis" (Reiss, 2000; McDermott, 1991; Matthews, 1989; Duschl, 1985)—a word, however, which appears to be more **slogan** than description, having been used off-and-on for decades. Nonetheless, educators both at schools and universities are troubled about declining enrollments (O'Meara, 2006)

The closure of physics and chemistry departments in countries such as the United Kingdom (McKee, 2005), poor performance on international tests (OECD, 2004: *PISA 2003*; IEA: *TIMSS 2003*), and the general unpopularity of lecture-based courses. The abandonment of science by numerous college students after taking introductory courses in physics and chemistry has been a cause of concern for several years (McDonnell, 2005; Rigden and Tobias, 1991). Among students themselves there is widespread perception that the

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10 Figures comparing the % changes in full-time undergraduate enrollment by field of study in Canada between 1991/92 and 1998/9 showed a 21% decline in physics, a 5% decline in chemistry and a 32% decline in mathematics enrollment. Yet during this same period there was an overall 3% increase in total full-time enrollment. (Trends in the United States showed similar declines). In contrast, other departments for the same period showed remarkable enrollment increases; computer science: 94%; forestry: 73%; geology: 56%; biology: 33%; nursing: 20%; engineering: 9% (O'Meara, 2006). A study of BC grade 12 provincial exam participation rates over a seven-year period (1997-2004) showed a consistent low rate of 14% (Phys), 23% (Chem) and 29% (Bio) of the total student body (Nashon and Nielsen, 2007). (An overview of physics education in Canada in general is described by McFarland and Hirsch; 1992).
content especially as presented in physics and chemistry classes is largely formalistic, dogmatic, unexciting and irrelevant, as evidenced in several countries (Canada: Brouwer et al., 1999; US: McDonnell, 2005; Germany: Reiss, 2000; Norway: Angell et al., 2004; Denmark: Nielsen and Thomsen, 1990). This identifies the first of three problems central to science education which foreground this chapter. I shall call it the problem of meaning as related to relevance and non-transferability: the common inability of students (and also citizens) to transfer their classroom or previously attained scientific knowledge to issues and problems related to their everyday lives. This is the view from the inside, from those within educational institutions: the teachers and students effected by curricular demands and designs, teaching and learning styles, as well as an educational system long dominated by traditional instruction based on “structure of the discipline”, “textbook science” and standardized testing (although it comes as no surprise to science educational researchers who have instead emphasized the need for science-technology-society (STS) context and curricular themes for over 20 years now; Yager, 1996; Roberts, 1982).

This predicament is not unique to science education, of course, and has been identified as a general dilemma with public schooling (Ungerleider, 2003; Egan, 1997; Gardner, 1991). In brief, Egan (1997) understands the issue to be a combination of at least three conflicting goals of education in schools and society (with their underlying educational theories) along with a failure to consider appropriate age-developmental (emotive-cognitive) understandings in students. Gardner (1991) also sees the problem associated with a combination of factors: the failure to recognize students’ preconceptions which they bring to classrooms; narrow focus of schooling on abstract knowledge at the expense of true understanding, and elevating the cognitive domain at the expense of developing a variety of other intelligences, especially the emotional domain. Ungerleider zeros in on the curriculum as the primary culprit:

The problem is the curriculum. The curriculum of the public school has become bloated, fragmented, mired in trivia, and short on ideas. It does not demand that students connect what they learn with anything else. It does not challenge them to reach their limits. The curriculum stifles curiosity. Although it demands effort, it does not reward deep thought (2003, p.105).
Identified here, albeit in simple terms, are important issues relating to meaning and use; knowledge versus understanding; and the proper status and location of disciplinary knowledge (or a teacher's content knowledge CK) within science teaching and curriculum that could possibly enable such understanding to take place, all of which will need to be addressed further. Let us move to the subject of understanding for the moment and examine this briefly as it comprises another problem of science education (while recognizing its ties to the previous issue of meaning and use). It is true—and accepted as self-evident among teachers and the wider public—that science education of the specialized disciplines at the upper secondary and undergraduate levels does indeed impart degrees of technical content proficiency. But what is not so well-known among teachers and the public—although it has been disseminated for decades in science educational research journals—is that such acquired formal knowledge remains largely theoretical, without context and "inert" in students' minds when they leave their science classrooms. The view from within the science education research community has established without a doubt "the [predominant] failure of science teaching to disturb ingrained beliefs" among learners. Students, in fact, "often live in two worlds, one for the science exam, another for everyday life. This is alarmingly illustrated in recent American surveys showing that belief in astrology is very little effected by completion of an American science degree" (Matthews, 1989, p.5). This "two minds outcome" as it is sometimes referred to—and one that would surely disturb teachers and cause much unease among the public if it was more broadly recognized—is the inability of students trained within the same discipline to solve basic problems in different contexts and attain deeper conceptual understanding of the topics commonly taught in classroom science\footnote{\footnote{Examples include: F = MA (for use in schools) versus "motion implies force" (for use in the real world); natural selection versus creationism; and the kinetic-molecular theory versus the caloric theory of heat" (Wandersee et al., 1994, p.190). Not all learning will necessarily result in this kind of unintended "two mind-set" outcome, though it is pervasive. A "mixed-outcome" where the student reconciles the two views in a hybrid is also possible.}}, but in other subjects as well (Gardner, 1991).

Secondary- and college-level physics and chemistry students in numerous studies have exhibited this in the past 30 years and some examples will illustrate this by-now widely accepted problem of science learning (McDermott and Redish, 1999; Nakhleh, 1992; Duit \textit{et al.}, 1992; McDermott, 1984). Physics students are able to successfully
solve mechanics problems using Newton’s second law \((F = ma)\), and even obtain high scores as measured by standardized tests, but most tend to revert back to “common sense” reasoning and Aristotelian-type conceptions of forces and motion once outside of the “text-test” framework (Palmer, 1997; Hestenes \textit{et al.}, 1992; McCloskey, 1983; DiSessa, 1982). In chemistry, researchers have found that profound misunderstandings persist throughout schooling, from elementary through to undergraduate, and occasionally even into graduate school, about atomic and kinetic molecular theory. A significant portion of students continue to hold to ideas which appear based on their everyday experiences, such as insisting that the atoms of metals themselves expand when a metal rod is heated, or that the bubbles rising in a pot of boiling water are comprised of air or hydrogen (Nakhleh, 1992; Osborne and Freyberg, 1985). Some of these conceptions bear remarkable resemblance to the Aristotelean-type ideas of early scientists in the history of chemistry, for instance that gases are weightless substances (Mas \textit{et al.}, 1987). This situation can be traced back to the apparent pedagogical failings of educational institutions and academic science departments to properly prepare teachers.

According to an early study by McDermott (1984, p.31), the research clearly indicates, that many students emerge from their study of physics or physical science without a functional understanding of some elementary but fundamental concepts. Similar problems exist at all levels of education, with little difference between high-school and college students. Of particular concern is the apparent failure of universities to help precollege teachers develop a sound conceptual understanding of the material they are expected to teach.\(^{12}\)

Therefore, one could argue post-secondary instructors have equally not been adequately prepared for the obstacles raised by the pedagogy of teaching and learning science content as structured by science academic disciplines in introductory undergraduate courses (Hestenes, 1998). These serious impediments to true understanding are due in large degree to the limitations of teaching de-contextualized, abstract knowledge along with an algorithmic (solely numerical) problem-solving approach and ignoring both everyday or techno-social problems and the \textit{nature of science}

\(^{12}\) Note that although this insight is several decades old, there has been little improvement in the situation (McDermott and Reddish, 1999; Mestre, 1991), although Lillian McDermott, her Physics Education Research group (PER) and others (Hake, 1998), have made significant research contributions towards alleviating this on-going problem (McDermott \textit{et al.}, 2006).
emphasis, while assuming a trouble-free transmission or ‘morse-code’ notion of language, so typical of textbook-dominated science learning at both the high school and undergraduate stages in physics and chemistry pedagogy (Niaz, 2005; Stinner, 2003; Nakhleh and Mitchell, 1993; Mestre, 1991). Furthermore, as may have become evident, this problem is directly connected to—and also supported by the research literature amassed over the years on—students’ “misconceptions” and “alternative frameworks” which they invariably bring with them to classrooms (and rarely discard), and which are too often ignored by teachers during traditional instruction (Wandersee et al., 1994; Duit, Goldberg and Niedderer, 1992; Hestenes et al., 1992; Mestre, 1991; Zoller, 1990; Osborne and Freyberg, 1985; Driver and Erickson, 1983). I shall call this the problem of context and conceptual understanding in the physical sciences.

A third problem associated with science education has come to be identified by those viewing education primarily, but not exclusively, from the outside, those concerned with the public understanding of science (which now has its own academic journal by that name): scientific institutions, think-tanks, government agencies, business and corporate interests, and concerned citizens in general. This is the problem of science literacy—although science educators as well have for decades been preoccupied with this problem from their own reasons and concerns. A reasonably high level of scientific literacy among citizens has come to be seen by many within modern societies—both Western and non-Western, whether developed or developing—as of vital importance for maintaining both economic and medical health but also democratic policy-making and environmental sustainability, because of the intimate ways these are wedded to, and dependent upon, techno-scientific innovations (McEneaney, 2003). It has, in fact, been understood as a principal objective of science education since the 1950s—by some arguably as early as 1900 (DeBoer, 2000)—and is often touted in the media as the key component in today’s “knowledge economy”. Unfortunately the very low levels of scientific literacy as evidenced by the public—around 8 to 10% (although highly

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13 Laugksch (2000) has identified four major interest groups concerned with this very important and controversial topic: science educators, public opinion researchers, sociologists of science and those involved with informal and nonformal science education (science museums and exhibitions, zoos, science journalists, writers and film makers, etc). The agents I have listed should therefore be identified as a fifth group (this diverse, powerful and influential group could possibly be labeled “socio-economic”), although there are overlapping interests with groups two, three and four. My preoccupation is group one and two.
dependent upon how it is defined and measured)—in numerous surveys taken in several Western countries, has remained remarkably and disappointingly unchanged over the past several decades (Miller, 1998; 1996).

So one can safely conclude that regardless from which of three current important perspectives science education is viewed (whether from inside institutions themselves, or from within the research community itself, or from outside interests), there is a common perception of an unsatisfactory state of affairs and hence renewed calls for significant reform(s). Unfortunately, any view from the present vantage tends to the myopic; it is rarely adequate to recognize either the roots or the wider dimensions of fundamental problems. What is required is broader historico-philosophical analysis.

It has become an accepted state of affairs for those involved in science education that the call for reforms has been ongoing for almost a century, with each new movement seeking to reshape, and in some cases successfully redefining, the identity and goals of the discipline (Keeves and Aikenhead, 1995; Bybee and DeBoer, 1994). The newer reformist movements, those since WW2, have frequently followed the periodic return of “crisis-talk” (first in 1957, then in the early 1980s and again in the late 1990s)\(^\text{14}\), and illustrate the relation, if not the dependence, of science education on outside societal forces or groups and their interests (“stakeholders”) who also seek to mark out the nature of the discipline (e.g. state-run Ministries; academic scientists and business leaders; parents, politicians and policy-makers; Laugksch, 2000; Fensham, 1997). For such talk is usually precipitated by socio-economic, political and cultural calamities external to the science education community—and for various diverse reasons which are not altogether justifiable it is nonetheless held accountable for aspects of these crises\(^\text{15}\)—and when

\(^{14}\) The cyclical return of such talk does indicate there is still something deeply amiss with ongoing science education and which both periods of so-called reforms—the scientist/discipline-centered curricular reforms of the 1950s/60s and the STS inspired movement of the 1980s—have failed to adequately address and rightly resolve. For a skeptical look at earlier crisis-talk see Klopfer and Champagne (1990).

\(^{15}\) There are compelling arguments which indicate that the widely accepted correlation between improved secondary science education—and hence assumed improved literacy—and the supposed benefits accrued for either national economic performance or increased critical citizenship are largely illusory (Shamos, 1995). An in-depth global study undertaken by Drori (2000) on the widely assumed ‘policy model of science education for economic development’ highlights the many methodological problems associated with the empirical studies and economic models which render any connection between the two “unreliable” (p.31). The empirical evidence is inconclusive at best, states Drori, regardless of claims to the contrary (and as charged against the competency of teachers and school science throughout the 1980s). And the burden of ensuring a “scientific pipeline” for future supply of specialists falls primarily to post-secondary pedagogy.
compounded by the increased attention given to comparing international standardized tests (such as TIMSS and PISA, the stimulus of the latest crisis-talk) have combined together to target the curricula and competency of school science education (Donnelly and Jenkins, 2001; Solomon, 1999; Shamos, 1995). Although the evaluation of the outcomes and significance of these test results are controversial—including what they may or may not reveal about science literacy levels (Sjøberg, 2003; Fensham, 2002; Jenkins, 2001; Gibbs and Fox, 1999)—in general one can readily admit that there has been little change in secondary and tertiary classrooms over the decades in Western countries (whether in textbooks or in instruction; Osborne and Dillon, 2008; van den Akker, 1998). And this despite reform intents and the cyclical ringing of alarmist bells, and despite the by-now four decades worth of significant research and development in the worldwide science education research community.¹⁶ At the tertiary level in particular the need to reform introductory science classes has received increased attention (Sunal et al., 2004), especially with some new findings in Physics Education Research (PER) indicating that the dominant textbook- and lecture-based instruction in large classrooms is unwittingly producing an anti-scientific mind.¹⁷

Why research within science education generally tends to have so little impact on classrooms is due to various factors and continues to occupy the community as a serious problem (Boersma et al., 2005; Jenkins, 2001; Millar et al., 2000). Another important reason, cautiously suggested here, is the omission of developing any kind of metatheory for the discipline. Such an educational failure could help account for why curricular reforms are particularly vulnerable to the political whims (or “ideologies”) of various

¹⁶ Note the following in America: “More than 4,000 articles and books in the past 30 years have declared some sort of crisis in schools, but these scholars rarely bothered to spell out what cataclysm was imminent. Each episode has also eaten away at public confidence in schools, which fell 38% from 1973 to 1996, according to surveys by the National Opinion Research Center . . . nearly 1000 laws [have] been passed since the 1970s to force reforms on schools—but have made little change in what students learn” (Gibbs and Fox, 1999, p.87). Surprisingly, a lead investigator of the U.S. National Science Education Standards (NSES) document is quoted as saying (on p.88) he doubts high scores on TIMSS correlates at all with being scientifically literate—precisely because they focus narrowly on formal content knowledge. Here one clearly notes the contested meaning of the term itself.

¹⁷ Yet despite these disturbing findings researchers in these newer fields of study (including Chemical Education Research, or CER) still struggle uphill for respect and acceptance in their academic departments, where educational studies and research continue to be afforded a low priority (Gilbert et al., 2004; Hestenes, 1998).
stakeholder groups, an enduring situation several researchers have taken notice of (Aikenhead, 2007; Fensham, 2002; Donnelly and Jenkins, 2001).^{18} What has transpired, and been reluctantly admitted, is that several conflicting redefinitions of the meaning of "scientific literacy"—long seen as the fundamental goal of science education (both within and without the community)—has occurred over this extended time period, though unfortunately with little consensus on the part of the community itself; "with one exception: everyone agrees that students can’t be scientifically literate if they don’t know any science subject matter" (Roberts, 2007, p.735).^{19} This has been the major contributing factor to the ongoing disputes surrounding curriculum programmes, content selection, and the choice of suitable targets and their evaluation when constructing appropriate measurement instruments, whether for standardized tests or for public understanding surveys (DeBoer, 2000; Laugksch, 2000; Shamos, 1995; Bauer, 1992). This lamentable state of affairs although acknowledged cannot be ignored indefinitely. Jenkins (1992, p.237) has made the observation:

In essence, therefore, scrutiny of the notion of scientific literacy raises in an acute form the question of what counts as science education. It is perhaps worth recalling, therefore, that, in a democracy, the answer to this question is socially, rather than academically or theoretically determined.

One can go along with the first part of this view while taking serious issue with the second. Though one can readily acknowledge that since school science exists both as a public institution and as an educational undertaking it must be responsive to its sociocultural environment and the interests of stakeholders, it does not therefore follow that

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^{18} "We must not forget that curriculum decisions are first and foremost political decisions. Research can inform curriculum decision-making, but the rational, evidence–based findings of research tend to wilt in the presence of ideologies, as curriculum choices are made within specific school jurisdictions, most often favoring the status quo" (Aikenhead, 2007, p. 880; original italics).

^{19} In this recent important and comprehensive review, Roberts has coined the categories "vision one" and "vision two" to account for two major competing images of science literacy behind several curricular reforms. The former designates those conceptions of science literacy which are "internally oriented", that is, towards science as a knowledge- and inquiry-based discipline and including the image of science education as heavily influenced by the identity, demands and conceptions of the profession. The latter vision, alternatively, is "outward looking", towards the application, limitation and critical appraisal of science in society, the image influenced instead by the needs of society and the majority of students not headed for professional science-based careers. Here the question of the "social relevance" of the curriculum is paramount. He maintains that while the second vision can encompass the first the opposite is not true. My contribution, spearheading Egan’s ideas, can be considered a third option for literacy: "vision three".
science education or literacy must be primarily socially determined—this is to undervalue if not to undercut its educational merit. A major argument of this Thesis is to undermine such a notion (because such a determination usually results in an impasse), and insist to the contrary that the answer to the question must first be addressed educationally, to be educational-philosophically determined, and afterwards socially negotiated.

Internally the research community has had considerably more success (in large measure because it has limited its focus to localized empirical studies) in addressing the "two-minds" outcome of domain-specific subject topics in contemporary instruction relating to canonical knowledge (e.g. kinematics, chemical bonding or diffusion)—where many students enter and leave classrooms with their alternative conceptions typically intact

—through various reform tactics: "interactive classrooms"; new "inquiry" techniques; conceptual change strategies; micro-computer based simulations (MBL), and others. And although the research on conceptual change is now extensive and formidable, much still remains to be answered about how to improve science learning (Scott et al., 2007; Erickson, 2000; Wandersee et al., 1994).

Indeed, the majority of science education research work seems focused on such content-based "technical" and learning studies (Lee et al., 2009; Hodson, 2003; Gunstone and White, 2000). Indeed, Gunstone and White have made the case that science education has 'progressed' as a discipline because of several principles discovered through research work related to alternative conceptions and student learning. As necessary and important as these are individually there still exists considerable criticism concerning the image of science that underlies such studies with their focus on formal, decontextualized scientific knowledge—the

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20 Indeed some studies suggest students’ conceptions of motion, heat, light, electricity, genes, atoms, and many others, are only rarely adjusted or replaced by canonical ones after traditional instruction—although it can be admitted that the degree of the tenaciousness varies considerably according to level, subject and the alternative kinds of instructional strategies employed (Wandersee et al., 1994).

21 As an example of the scope of what has gone on in Physics Education Research (PER) alone over a 20-year period—and moreover to spotlight as evidence for the critique which follows—see McDermott and Reddish (1999). An exception is Kalman (2008). See also the earlier critique by Cushing (1989) of tertiary physics education targeting its ongoing neglect of incorporating important aspects of NoS into curricula.

22 According to their comprehensive survey of research topics 2003-2007 for three common journals (USE, SE, JRST) the two categories "learning-conception" and "learning-contexts" made up the top two at 38.8%. If one includes the category "Teaching" (13.9%) these top three give 52.7%. (Although the authors note a decline in conceptual change publications compared with their previous search 1998-2002). The "philosophy, history, nature of science" research category showed a paltry 8.2% of publications for these journals (a noteworthy decline from the previous 4-year period of 16%).
mainstay of most school and college learning—and they serve at best as intermediate and not final aims, of ordinary chemistry and physics education, etc., in particular, and of science education in general. Nor can they assume to have skirted the wider literacy question; quite the contrary, such studies implicitly commit themselves to a very narrow conception ("technical training"), for they are satisfied with a restricted (and ahistorical) understanding of formal content knowledge within isolated and specialized disciplines—a conception which has come under noteworthy attack for decades now. 23

Related to this, one can identify two more criticisms which immediately come to the fore: the limitation with respect to context in which the subject content knowledge is presented and assumptions about the nature of content knowledge—the former a pedagogical issue and the latter an epistemological one. The issue of "context" has only recently come to concern physics and chemistry researchers (Gilbert, 2006; Finkelstein, 2005; Redish, 1999). Klassen (2006) has provided five contexts that are important for learning (theoretical, practical, social, historical and affective) and has developed a story-driven contextual model. As discussed later, the issue of context as narrative especially as explicated by an educational metatheory will be seen as paramount for successful learning. Furthermore, such metatheories will purposely problematize the disciplinary-based content knowledge for educational purposes. (The epistemological problem will be dealt with separately in Chapter 4).

The interplay of internal versus external-motivated reforms in science education is long and fascinating, involving a complex and controversial relationship among diverse social groups (claiming disparate interests, goals and definitions of literacy), the character of which has overlapped with the conflicting and unresolved wider issues of the value and aims of public education, the complexity of techno-scientific impact on society, as well as the enduring academic quarrels over the nature of science (NoS). These conflicts are probably inevitable, and pertinent questions remain to be answered as to whether or

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23 Because the ongoing perception of science education at the upper levels worldwide is almost exclusively seen as technical pre-professional training (TPT) rather than a broader conception of education either about science or about science and society, science teacher training along with classrooms at secondary and tertiary levels continue to ignore the epistemology, social practices and histories of science. They are almost universally failing, as others have pointed out, to bring to fruition in students' minds a more authentic view of science: the development of how scientific ideas change; the nature of scientific reasoning and inquiry (also modeling); the methodologies of science and its epistemology—also termed nature of science (NoS) discourse (Lederman, 2007; 1998; Yager, 1996; Duschl, 1994; Bauer, 1992).
not they are in fact intractable given the intersection of several other equally substantive dimensions, especially the following:

- the fact that science is historically and culturally dynamic and exhibits itself to us three-fold, as an accumulated body of knowledge, but especially as a knowledge generating and techno-social enterprise—the impact on societies and cultures of which has both positive and negative consequences (different reform “waves” have laid stress on one or the other of these aspects to be taken as the key factor in defining “literacy”).
- the implicit educational project (inherited from progressivism and the liberal education tradition, which remains active to some degree), geared at enabling learners to develop their potential as autonomous individuals, including cultivating creativity and critical thinking skills (stressed as the “humanistic aspect” at different times in reforms).
- the ever-present desire by diverse social interest groups to orientate education towards either socio-political or socio-economic useful ends (utility arguments)—what can be called the socialization imperative. Looking within the science education community (and ignoring for now those arguments from social groups without; Laugksch, 2000) this imperative is usually understood in two predominant ways: either as preparation for professional and technical careers (as in the conventional curriculum) or, more commonly, for “civic responsibility” and “science for all”, with their assorted interpretations (those involved with HPS, STS, SSI reforms, “science for social action”; also the stated intentions of current Standards documents). This imperative has dogged science education since its inception (which Bybee and DeBoer (1994, p.358) label as the “social efficiency and effectiveness” and “national security” justification)—a required

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24 Today, with the push from parents and the business community stressing the need for creating a techno-scientific trained workforce for the competitive global “knowledge economy” the external pressures are again impinging upon science education and could possibly drive it towards a new “career focussed track” in ways most in the community (whether in traditional, STSE or Bildung circles) may find highly objectionable. Here one is wise to heed Apple’s (1992) concerns about the reduction of educational aims to economic utility. This is an example where internal/external interests could clash. Alternatively, the current concerns about global warming and environmental awareness among the public and business and the desire to transform curricular objectives accordingly, may represent a case where internal/external interests could overlap—as those within our community arguing for literacy as “socio-political action” have stressed (Roth and Barton, 2004; Hodson, 2003; Jenkins, 2000). The most typical case of congruence still continues to be the one between the interests of secondary science teachers and those of the external academic science community, by simple virtue of academic teacher training. The close “ideological” relationship between these two social groups is occasionally bemoaned by some researchers, for example, by Fensham (2002).
demand of science teaching moreso than any other school subject—and one that several notable critics have countered is misguided and strains its capabilities as an educational endeavor (Jenkins, 1997; Shamos, 1995; Bauer, 1992). Yet it is one many educators are not willing to let go.

In any event, what seems to have been overlooked in its entirety is that three longstanding yet venerable and operative ideas in education—themselves inexorably embedded within science education (as sketched above)—could be undermining each other. As Egan (1997) has argued, schools in the West as educational projects are ineffectual primarily because they are caught between three chief objectives (or rationales) which effectively serve to check or undercut each others’ intended aims: whether to teach science for 1) intellectual development (knowledge), or 2) for individual fulfillment (character), or 3) for socio-economic benefit. (The first can be associated with the original knowledge-based educational project of Plato, the second with Rousseau, and the last is a cross-cultural and timeless expectation of most societies). When educational goals are examined historically these three are ubiquitous; they persistently present themselves albeit in different guises, and they certainly can be identified throughout science educational reform history (Bybee and DeBoer, 1994). Now no one normally

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25 In brief: socialization conflicts with the “Platonic” (knowledge-focused) project because the former seeks the conformity to values and beliefs of society while the latter encourages the questioning of these; Socialization also conflicts with the “Rousseauian project” since the latter argues that personal growth must conflict with social norms and needs. It sees growth and hence education in intrinsic terms instead of as utility for other socially defined ends. (Here exists the principal tension between the Bildung tradition and the dominating utility view of education and science literacy of the English-speaking world.) The Platonic and Rousseauian projects conflict because the former assumes an epistemological model of learning and development and the latter a psychological one. In the former ‘mind’ is created and the aim is knowledge, in the latter it develops naturally, requiring only proper guidance, and the aim is self-actualization.

26 A history of biology education clearly illustrates this: “A major theme throughout ... has been the continuing debates about its primary goal: whether it should be a science of life and emphasize knowledge or whether it should be a science of living and emphasize the personal needs of students and the social needs of society” (quoted in Roberts, p.5; Roberts and Oestman, 1998). Roberts though, does not recognize that there are three underlying educational conceptions at odds here; he defines instead the concept of “companion meanings” associated with curricula, and further, sees here only an example of two at odds.

27 As examples, the authors identify that “throughout the 19th century the goal of personal intellectual development [Rousseau] competed with the goal of learning science facts and information [Plato]” and that this competition “is evident in two curricular models that became popular ...” (p.365). Later, during the “progressive era” (p.369), “there was considerable lack of agreement on the goals“, whether “the knowledge goals” [Plato] or “application of subject matter to the lives of students” [social utility]. Here the community became “polarized” between extremes and how to organize the curriculum. Needless to say, a surprisingly similar debate flared up again during the 1980s “curricular wars", and remains with us today.
holds exclusively to one or the other, although usually one or the other is emphasized over the other two at a given time (depending upon the defined “crisis” at hand and under influence of respective social group interests) and the modern school and indeed many Standards documents aim at a sort of balance between them. Egan maintains, however, and I think this is the correct assessment, the attempts to achieve ‘balance’ are illusory, and must undermine the strengths of any one at the cost of the others. If this is indeed the case, then the impasse must encompass science education as well, whether one wishes to concede this or not. What is required as a way out of this stalemate, argues Egan, is for education to mature and develop its own discipline-specific theory. This would, in turn, go a long way (perhaps not all the way), in resolving the internal-external tensions between diverse social group ideologies and related curricular paradigms that have shaped, and still shape, the contours of the science educational endeavor.

The History and Philosophy of Science (HPS) reform movement has a history over a century old too, and has taken part to differing degrees in the debates defining the aims of science education, including scientific literacy, and hence revising curriculum and instruction accordingly (reviews are given in Duschl, 1994; Matthews, 1994). It has had only partial success, however, since its agenda must still compete with alternative and well-entrenched curricular “projects”—though “paradigms” is a better word—within the actual schooled community (the main ones being traditionalist; progressivist; STS;

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28 Walker and Soltis (1986/1997) reach a similar conclusion when assessing these three chief conflicting goals of education which drive curriculum reform efforts.

29 It is to assume one can apply them as principles while ignoring their underlying theoretical frameworks. “The trouble is, each of them has significant problems separately, and together they do not blend into a coherent curriculum. We are so used to mangled curricula, however, that their fundamental incoherencies are accepted as necessary ‘tensions’ produced by the competition of ‘stakeholders’” (1997, p.206).

30 I cite here the example from Bybee and Ben-Zvi (1998, p.488): “Using the term ‘scientific literacy’ implies a general education approach for the science curriculum. General education suggests that part of a student’s education that emphasizes an orientation towards personal development and citizenship ... [it] suggests that one should begin the design of a program by asking what it is that a student ought to know, value, and do as a citizen.” They seem unaware that ‘personal development’ and ‘citizenship’ can seriously conflict. They further appear to assume that instrumentalized education for ‘citizenship’ as both definition and goal does not entail considerably difficulties in its own right. (Here one only need peruse the philosophy of education literature! For example, see Mitchell, 2001). They continue: “We contrast this approach to designing a science curriculum with the initial effort in which individuals ask what it is about physics, chemistry, biology ... that students should learn.” Here they explicitly devalue the Platonic project. As seen later, “literacy” is here defined in accordance with conceptions beholden to the STS paradigm.
Standards’ movement). Although this term as popularized by Kuhn (1970) has some drawbacks, it serves the purpose for which I intend to use it (Shulman, 1986). What is missing in all science education paradigms though, are defining high-level educational theories that could inform and drive them. More recently a host of other reformist research approaches (e.g. to integrate social activism, or incorporate gender, multicultural and global issues, among others) have been demanding increased attention while pressing for their own goals and targeting their preferred issues. And although the latest school Standards documents (in so far as they are implemented policy documents) in the English-speaking nations show considerable overlap on several topics, and in particular have emphasized the significance of incorporating the nature of science (NoS) for a broader and more accurate understanding of science (to the relief of many HPS reformers; McComas and Olson, 1998), this NoS goal nonetheless often runs at cross-purposes to others—including competing “visions” for science education (Roberts, 2007). Some have even questioned the value of NoS instruction, including the epistemic basis of so-called “Western science” (Rudolph, 2000). As a consequence, both a conceptual and value-based impasse between the alternative paradigms has come about. This tends to deadlock attempts at practical implementation, affords traditionalism the

31 One must tread carefully here. It is helpful to distinguish between “research programmes” (Lakatos, 1970) within the science education research community and “paradigms”—often implicit and hidden—that encompass the beliefs, instruction, culture and curricula of practitioners in classrooms. The latter can be influenced by the former community in different ways. Another distinction should include social groups and their “ideologies” which inhabit either university-driven research programs or classroom communities, although an alliance between the two can certainly exist (e.g. STS researchers and STS teachers). For a useful discussion of social groups and their interests, see Ernest (1991); for ideology analysis see Saether (2003). For a discussion of the dominating community research programmes see Anderson (2007), Tsapartis (2001) and Erickson (2000).

32 Namely, as a tradition influenced by key theories, texts and authorities that guide how groups of scholars, scientists or practitioners see evidence, solve problems, perform research and communicate with each other over a time period. His revised term for it as a “disciplinary matrix” serves equally well. But I do not follow him in his strict elaboration of the term defined as a single dominating one for the sciences. Shulman has argued that due to the richness and complexity of fields like education and the social sciences their “mature stage” of development might instead be characterized by several leading and co-competing paradigms.

33 This omission does put into serious question my use of the term. No matter in what field where the term is commonly applied it is generally understood that at least one high-level theory characterizes the paradigm of the discipline, although a few may be in competition (e.g. Newton, Einstein in physics; Darwin in evolutionary biology; Skinner, Piaget and Ausubel in psychology; Marx, Weber in sociology, etc.).

34 See Good and Shymansky (2001) for how statements concerning NoS in both the US Standards documents Benchmarks and NSES can be read from opposing modernist or postmodernist perspectives.
default position of the status quo, and at minimum it undermines the potential of what HPS reformers seek to accomplish.

This becomes noticeable if we briefly compare HPS to its two major curricular "competitors": STS and the conventional, specialist paradigm. While there has been some fruitful intercourse in the past between STS and HPS reformers (especially their mutual humanistic emphasis), those within the two paradigms now seem to be drifting apart given the divergence of views on NoS, the goals of science education and the notion of literacy (Turner and Sullenger, 1999; Aikenhead, 1997)—especially with the relocation of some former researchers within STS shifting towards a kind of "political activism", some even flirting with relativist and postmodernist ideas (Roth and Desautels, 2002; Loving, 1997). It would seem a critical mass of incommensurability has been reached. There are researchers who now argue in fact that since STS has not lived up to its promise of properly engaging students with science and society concerns it is time to move "beyond STS" (Zeidler et al., 2005). In essence, STS "may be an underdeveloped idea in search of a theory" (p. 358). Shamos (1995) had already made this charge a decade earlier. Comparing HPS with the traditional academic (or specialist) paradigm, it is quite apparent that at the upper levels this paradigm (social group, curricula, textbooks, literacy conception and practices) remains deeply entrenched, where an outlook prevails that continues to undervalue the epistemology and history of science (also the social practices of contemporary science), while overestimating the efficacy of lab-based

35 It is one thing to say a broader and more authentic science education should include the occasional critical discussion involving the oft neglected nature of 'frontier science' and related socio-scientific issues, and that the literacy definition could possibly comprise some aspect of this; it is quite another to demand that the discipline and literacy should be defined by and structured around frontier science, socio-technological issues or even socio-political action exclusively. Such a radical approach, as Shamos has insightfully remarked, usually skirts the core question of how the science itself should be taught and learned. And there is certainly no need here to repeat the earlier and still unresolved debate of the 1980s "curricular wars", the conflict between two major curriculum models: between those who sought (and still seek) to organize curriculum around STS type-themes and those who resist any such context not heavily tied to the subject disciplines and knowledge structures (see Bybee and DeBoer, 1994, pp.378-80). Besides the fact that this debate looks suspiciously like the older version of the 'Platonic' academic programme (i.e. Hirst, 1974) versus socialization, it could certainly have used some philosophical-historical insight.

36 Those within the recent Science-Societal Issues (SSI) approach argue that STS has failed to properly account for an explicit NoS discussion, for scientific argumentation and for ethical and cultural values connected with techno-scientific impact issues, and, more importantly, it lacks a theoretical framework.

37 Turner and Sullenger (1999, p.15) also note that the STS camp has suffered from internal tensions because of the inability to articulate what its proper goal should be, torn between four different approaches of cultural, practical action, technocratic or interdisciplinary issues-based emphases or projects. One notices again the consequences of neglecting to first specify one's educational theory.
“cookbook” inquiry and content acquisition in decontextualized settings (see Lederman, 1998). Although the new worldwide HPS movement is now twenty-years-old and some inroads are occurring at the secondary level (as presentations at IHPST conferences attest to), at the tertiary level little appears to have changed (Mason and Gilbert, 2004; Galili and Hazan, 2001). Yet here too, an educational theory is missing, indeed an educational philosophy, to justify the practices and curricula in these classrooms—although everyone seems agreed that its main purpose is induction into academic science (Jenkins, 2000; Fensham, 1997; Shamos, 1995).39

What is characteristic of both traditionalism and STS, speaking generally, is that each paradigm embraces social groups holding competing conceptions of science literacy that, taken alone, are exclusive and form oppositions—which Roberts (2007) has perceptively described as ‘vision I’ and ‘vision II’, respectively. Put in practical terms this stark contrast has several negative consequences for science teachers, for they are forced to choose between options they would prefer to avoid: the choice of mainly teaching science either as “knowledge of” (Platonic project) or as “knowledge for” (socialization); preparing their students primarily for science-oriented vocations or for “active citizenship”; moreover, it forces a choice in their allegiance to two vital social groups, either to the academic science community or to the science education community (that is, to one particular sub-group within that community)—unfortunately by identity, by training and by calling (by appeal of their specialty and by request of their profession as educators) this divorce is not possible, nor should they be placed in such a quandary.

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38 Often seen in either naïve inductivist or falsificationist terms (Bauer, 1992). See also Claxton (1997).
39 This induction does include three sub-purposes as “curriculum emphases”, which Roberts (1982) had identified as the requirement to: i) build a “Solid foundation” (logic of subject topics in succeeding years), ii) give “Correct explanations” (“products”), and iii) ensure “Scientific skill development” (“processes”). These “emphases” furthermore, can be directly linked to Eisner’s (1985) “curricular orientations”, being influenced by “academic rationalism”, “curriculum as technology” and “development of cognitive processes” as three of his five predominant orientations that have heavily influenced science curriculum decision-making since inception of the 1960s traditionalist, academic paradigm (see Duschl, 1990, p.67).
Again, a “balance” does not appear an option with exclusivist-type paradigms. Yet this kind of dilemma seems destined to occur when educational theories are lacking, when teachers are not philosophically equipped to grapple with competing curricular visions, and when external social groups on top of well-intentioned reformers (all beholden by conviction to their own educational ideologies) unwittingly initiate with science teachers (Pedretti et al., 2008).

2.3. The Need for Philosophy of Science Education and Educational Theory

At issue in my view, and as has become apparent so far, is there exists a much greater and fundamental problem plaguing school science education as a discipline. It goes deeper than “crisis-talk”, disagreements over conceptual change strategies and learning theories, debates over literacy, goals and how to balance competing group interests, including the disparate perspectives on the worth of “Western science” in terms of questioning its epistemology, objectivity and universality. At bottom, what should have become apparent but remains hardly noticed is that the HPS movement suffers from not having developed an overarching conception of the educational endeavor (or “philosophy” if you prefer) behind its intended reforms—something it shares with all other reformist projects and their various and changing curricular “emphases” (Roberts, 1982). Hence, while it partakes in the debates (intrinsic versus instrumental goals; the meaning of science literacy or constructivism, curriculum content choice, etc.) it remains hampered and cannot rise above them. My accent on “educational theory” therefore, equally entails the conviction that science education requires a conceptual reorientation—it needs to re-shift its theoretical discourse towards the philosophy of education in fundamental ways, in particular the need to develop the sub-discipline philosophy of

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40 It might be objected that teachers normally attempt to address valid aspects of both paradigms and allow for individual differences and needs. While this may be true in general, it fails to acknowledge that curriculum is prescribed and that traditionalism is by far the status quo—hence there is often little maneuverability between desired and dictated curriculum. Exactly for these reasons Jenkins (2000) has called for a “paradigm shift” in science education. However, as I see it, even if this was successful, the traditionalist paradigm would nonetheless remain as an effective competitor. (“Paradigm” is here understood not in the strict Kuhnian sense but, again, according to Shulman, 1986).

41 The paper by Pedretti et al., is revealing on several levels, not least of all what is exposed here about their social group “ideology”, predisposed to the validity of the STSE paradigm (especially among researchers in Canada), as the only legitimate educational game in town.
science education. This new field of inquiry could initially consider what Ernest (1991) had already outlined in his work for a “philosophy of mathematics education” (although some have argued his project is more about sociology than philosophy). It can be considered a truism that modern science education has tended overall to ignore philosophy for psychology, especially its theories of learning and development which still dominate education research (Fensham, 2004; Duit and Treagust, 1998; DeBoer, 1991). It is high time for science education to get its philosophical house in order, and hence, to return to thinking about its foundational problems and goals.

When examining the newest Handbook of Research (Abell and Lederman, 2007) as well as the two earlier defining and comprehensive Handbooks on science education (Fraser and Tobin, 1998; Gabel, 1994), which together can be taken to represent the “best thinking” in the discipline, one is amazed to discover a complete lack of reference to philosophy of education, or in fact any discussion related to educational philosophical theory. This absence is further attested by recent publications of European Handbooks of research in the field (Boersma et al., 2005; Psillos et al., 2003). Fensham’s important book Defining an Identity (2004), which surveys researchers and the scope of their work over four decades (as mentioned previously), illustrates this glaring omission best. Likewise, even a cursory perusal of individual reform-minded literature shows a near complete lack of acknowledgement of terms like “theory of education” or “educational philosophy”. This is equally true of reformist-type Standards documents in both the United States (e.g. AAAS, 1993) and Canada (Council of Ministers, 1997). (Clearly, statements of standards, a list of goals and principles and mandated policy documents while useful cannot in the end substitute for an educational philosophy. Such items

42 I mention here Roberts and Russell (1975), who much earlier argued for the need of philosophical informal analysis for examining common concepts (like “teaching” and “authority”).

43 He foregrounds a useful analysis of educational “ideologies”, including their connection to five kinds of social groups. (Note Table 6.3, p.138). The ‘philosophy’ he offers is primarily social-constructivism.

44 This is not meant to imply there has not been some important research work which has sought to clarify the differences between the two for science educational purposes, although such literature tends to favour conceptual change research, where the “philosophy” in question usually refers to philosophy of science (Duschl and Hamilton, 1992; Duschl et al., 1990).

45 Indeed, there exists little reference to “philosophy of education”, “educational theory” or just plain “philosophy” (Jenkins, 2000; 1992; Millar et al., 2000; Hurd, 2000; 1994; Shymansky and Kyle, 1992). When scanning for the reference of such terms in the community’s established research journals (e.g. Science Education; Journal of Research in Science Teaching) it quickly becomes apparent that when, for example, “philosophy of education” is cited the sense is rarely linked to that discipline and its concerns.
though usually contain implicit philosophical messages and telegraph explicit educational values.) This also holds for those interested in HPS reforms, although there have been exceptions: Matthews (1994) notes that the influential US National Science Foundation had already commented back in 1980 when criticizing school reforms that there existed a lack of "a sense of direction and a theory and philosophy which should provide guidance to curriculum development and instruction . . . " (p.31, quoting their report).

Nevertheless, what surprises is that one might expect a movement which has rightly focused on the need to integrate philosophy of science issues into science education would have been cognizant to a much greater extent of the need to inquire into a philosophy of science education as a framework within which to do the necessary education of the subject at hand, considering their educational focus. In almost all of those cases mentioned one proceeds as if philosophy of education, its related topics and issues are essentially irrelevant.

Jenkins (2001) has complained that the field of science education research has been too narrowly construed (in part as a critique directed at the two earlier Handbooks): it has been overly preoccupied with teaching and learning as practice, and thereto, suffers from "an over-technical and -instrumental approach" (p.11), at the expense of other perspectives, such as "the long-standing neglect of historical studies of science education, and more widely, of research not related directly to the teaching and/or learning of science" (p.12). This should certainly encompass explicit educational philosophical reflection on educational theory, which even he fails to mention. Along with the three predominant kinds of research in science education today—quantitative, qualitative-interpretive, and critical-emancipatory (Fensham, 2002; Kyle et al., 1992)—I would argue for the pressing need of a fourth, philosophical (or philosophic-historical).

In having stated the premise and identified the need of the discipline to partially shift its research focus towards more philosophical-based reflection and analysis I do not mean to imply that philosophy as a subject has been completely neglected. Such a view is obviously mistaken. Science education is known to have borrowed ideas from pedagogues and philosophers in the past (as examples, from Rousseau, Pestalozzi and

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46 One need simply scan the subject indexes of some important publications: Bevilacqua et al. (2001); Matthews (1994); Duschl (1994).

47 A recent significant contribution in this direction is the paper by Olesko (2006).
Herbart; DeBoer, 1991), yet most science teachers and too many researchers seem little aware, or even concerned to know, about this rich and extensive historical background. It has been said that the most significant philosophical impact, at least in North America, has come from the pragmatism of John Dewey, especially in the pre-WW2 “progressivist” era, and some authors continue to champion him today (Kruckenberg, 2006; Wong et al., 2001). Dewey’s ideas have also been presented at previous IHPST conferences (Briscoe, 1989; McCarty, 1989). There have certainly been other intermittent forays into philosophical terrain, some indirectly—for example, Stenhouse (1986) and Lemke (1990) who have looked to Wittgenstein and language studies for insight and reform ideas. Some more directly, such as Eger (1992), who has insightfully championed the worth of Gadamer’s (1975) philosophical hermeneutics for science educational reform. No doubt the most extensive and ongoing discussion which does include philosophy is the valuable but nonetheless limited focus on relevant themes in the philosophy of science for science education (Duschl and Hamilton, 1998, 1992; Matthews, 1994; Burbules and Linn, 1991).

Roberts and Russell (1975) were the first, however, to explicitly articulate the need for a shift from psychology towards philosophical analysis (drawing on the earlier work of Peters, Oakeshott and Scheffler in the philosophy of education, and Nagel and Toulmin in the philosophy of science). They argued for the necessity of science classroom teachers to select and develop philosophical-based “theoretical perspectives” when scrutinizing aspects of their science teaching—like the nature of authority, the kinds of arguments used in classrooms and the image of the nature of science—as well as the epistemology and metaphysics (“worldviews”) behind curricula. Their arguments were not limited to simply stating rationales, for they referred to several research cases at the time which exemplified such perspectives, and one can easily recognize how these different research emphases have grown and are being actively pursued today (especially by HPS reformers), although without awareness of their previous claims and examples. Since then Anderson (1992) has repeated the worth of including “philosophical

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48 A comparison of Egan and Dewey represents a fascinating clash of two contrasting conceptions or philosophies of education, one I cannot address here (see instead Polito, 2005; Egan, 2002). In passing one can disclose they are as incommensurate as are the fundamental differences which Bruner (1997) has identified between Piaget and Vygotsky in the field of psychology, both of whose developmental ideas have been raided by science educators to augment their learning theories (Duit and Treagust, 1998).
perspectives’ as one vital dimension (in a multiple perspective analysis) when discussing how to make curricular reforms more successful. Certainly earlier there has also been Scheffler (1970) who had stressed the importance of the direct inclusion of philosophy into aspects of science teaching and teacher training to help teachers become more critical of curriculum and reflective of their practice. Finally, Siegel (1992; 1989) and others have long argued for the value of enhancing critical thinking and “educating reason”—another research direction which today has grown and gained importance, emphasizing “practical reasoning” as well as scientific argumentation (Osborne et al., 2004; Bailin, 2002; Matthews, 1994; Brickhouse et al., 1993; Kuhn, 1993).

In sum: part of the present call for the shift in focus is to remind those in science education: a) that since it belongs to the sub-field of education it avoids educational philosophy at its own peril, and b) to insist on a greater awareness and appreciation of its own neglected historical philosophical roots. For if it is true that “philosophy of education is sometimes, and justly, accused of proceeding as if it had little or no past” (Blake et al., 2003, p.1), then this certainly rings true of science education. Lastly, c) to insist on the value and need to explicitly develop a philosophy “of” and “for” the discipline itself. As I presently envision it, such an internal reflection, as part of its self-conception and “research programme” (Lakatos), would seek to formulate appropriate educational theories, possibly a “grand” or “meta-theory”.

2.4. What is a Meta-theory?

The original emphasis on the requirement for a metatheory in education had been discussed by Aldridge et al. (1992) following the proposal first put forth by Egan in the early 1980s encompassing his critique of “scientific psychology” and the demand educational studies stake out independent territory (Egan, 1983). Simply put, a meta-theory is essentially a worldview or “paradigm” that seeks to formulate a coherent account of explanations of and prescriptions for a given range of phenomena within its specified conceptual framework; it has pre-established criteria for empirical interpretation

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49 This proposal certainly opposes the politically-driven trend in some countries, such as England, to downgrade the value of philosophy of education for teacher training purposes because of a mistaken belief and a myopic concern “insisting on the direct practical relevance of all educational courses” (Hirst, 2008b, p.309).
and judgments, and it directs research efforts along given lines within scientific or scholarly communities. In other words, it serves several roles: as the lens by which a community observes and reports data; as a semantic-net which provides meaning and conceptual order; and finally (characteristic for some social and applied sciences rather than for the natural sciences) as providing prescriptions for improvements and action. In the social sciences they can be classified into broad categories according to their makeup: as metaphysical, as political and economic, or as socio-linguistic. For our purposes, a metatheory in the disciplines of psychology and education “gives the big picture or may be described as the umbrella under which several theories of development or learning are classified together based on their commonalities regarding human nature” (Aldridge et al., 1992, p. 683). These authors suggest that four different psychological metatheories continue to influence educational practice in various ways depending upon how the individual-environment nexus of development and learning are described and evaluated: organismic (or biological; examples are Piaget, Werner, neo-Piagetians, psycho-analytic theories); mechanistic (Skinner and the behaviorist school); dialectical (influenced by Marx, Hegel and Vygotsky); and contextualism (based on the pragmatism of James, Dewey, and others). None of these though, are true educational metatheories, the authors insist. Nor is, it seems to me, cultural psychology, a relatively recent school of thought (Cole, 1996), and currently of lesser influence (although it goes back to the “second psychology” ideas of Wilhelm Wundt in the 1920s). It can be taken as a fifth metatheory, or alternately, may represent the convergence of two metatheories, those of socio-linguistics and dialectics.\footnote{In Bruning et al. (1995, p. 218; a standard textbook in teacher preparation courses for the use of cognitive psychology in instruction), the authors explicitly admit that three different kinds of constructivism (‘exogenous’, ‘endogenous’, and ‘dialectical’) are beholden to three different metatheories (mechanical, organismic and contextualist, respectively).}

What is important is to recall that any educational (meta-)theory must needs be a normative one, for it seeks to prescribe an educational process to ultimately yield a certain outcome or aim (Hirst, 1966). This is usually a kind of person or the ideal of what an educated individual should aspire to become given the values and dispositions to be cultivated and methods employed in the specified programme (Frankena, 1965). Further,\footnote{Many of these are characterized by descriptive and prescriptive elements (either implicit or explicit).}
it is in the worth of that final aim that the pedagogical methods of the educational project are justified, which traditionally have themselves been framed within the values and aspirations a society has deemed of ultimate importance: “The value of this end-product justifies the stages that lead toward its realization. Becoming a Spartan warrior justifies training in physical hardship. Becoming a Christian gentleman justifies exercise in patience and humility” (Egan, 1983, p.9; original italics). In Western civilization a succession of diverse aims or ideals have historically followed since the time of Ancient Greece and some of the greatest Western minds have been preoccupied with formulating various philosophies of education to define their respective ideal and suggest ways to realize it (Lucas, 1972): Plato: the (philosopher-king) man of knowledge; Aristotle: the “good” or “happy” active citizen; Augustine and Aquinas: the Christian saint; Locke: the successful Christian mercantile gentleman; Rousseau and romanticism: the natural development of self-actualization; Kant: the autonomous individual, self-rulled by moral “good will”; Dewey: personal and social “growth” through ever-changing experience.  

Frankena (1965) insists any philosophy of education must ask itself three basic questions: what dispositions (or “excellences”) to cultivate, how to cultivate them and why? When examining Egan (1983), he does appear to have these same generally in mind, though as I take it, he reformulates and generalizes them with a slight shift in accent. Instead of using terms like “dispositions to be cultivated” and “ideal” he talks in terms of “end-product” and “aims” while explicitly raising the important fourth component of development: it is of the essence of an educational theory, he writes, that it answer four key questions: what to teach? (curriculum), how to teach? (instruction), when to teach it? (stages of learner development), and most importantly, why to teach it?

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52 It should be noted that Dewey’s aim is among the least predetermined of the others, although it could reasonably be argued that Kant’s ideal is also dynamic in so far as he allows for education’s dual aim, the “perfecting” of man qua man plus the improvement of society and “the human race”. In addition, Frankena (1965, p.156) also notes that such a dual aim in Dewey could considerably conflict—that the expected growth of the individual and society may clash—in anticipation of Egan’s critique, which claims the clash is inevitable in so far as modern schooling is molded according to progressivist precepts. Alternatively, for Dewey, but also for Aristotle and Kant, such a possible conflict was thought to be reconcilable in principle.

53 Such questions are actually the purview of what is demanded of an educational theory. Philosophy of education properly understood is a much broader field of inquiry that encompasses an analysis of such theories and questions (Peters, 1966), which today usually overlaps with curriculum studies. Frankena seems to have been working with a constricted conception at the level of theory.
(specification of the end-product, aim or ideal). That said, the similarity in questions and intent is obvious.

Certainly these four questions appear on the surface to be matter-of-fact curricular questions and are asked by any competent teacher at the classroom level of practice; there however, the "what" is predetermined by the state- or department-sanctioned syllabus, the "how" is usually learned in situ with various instructional strategies and the "when" is often shaped by precepts taken from developmental psychology and, increasingly today, cognitive science. The "why" is taken to be, at best, a restricted focus on building a "solid foundation" and presenting correct knowledge of science products and processes (Roberts, 1982), or at worst, simply as the hoped-for achievement of "knowledge outcomes" based on the standardized test at the end of the course. (Although I believe most educational practitioners are more thoughtful about the objectives of their courses). At the intermediate level, these questions are also occasionally asked during professional curriculum planning within science departments and state ministries, where STS and HPS inspired reformers have also sought to spearhead policy change. Too often, though, policy is driven by professional or economic interests (Donnelly and Jenkins, 2001).

But to ask these questions at the higher theoretical (and foundational) level—the level which any philosophy of education will direct us to concentrate on, and which I suggest must be addressed by anyone wishing to critically reflect on curriculum—is to seek answers of a qualitatively different order. It is to ask basic questions of the quality and legitimacy of the education programme itself—including the courses embedded within—the justification of aims and content, the kind of educated mind or individual formed by such courses, who constructs and benefits from the project so defined?, etc. It is at this level that I maintain science education has been found wanting in not framing aspects of such a discussion in terms of the development of metatheory, instead of, say, "knowledge outcomes", "multicultural science", "science literacy", or "power-ideology" analysis (critical pedagogy; e.g. Barton and Yang, 2000; Apple, 1992). Moreover, Egan asserts because of the nature of the questions addressed at the higher level, psychology has little if anything to contribute to education, and the sooner educational practitioners
become aware of the autonomy and uniqueness of their discipline, the better off and more successful their enterprise will be.\textsuperscript{54}

The term “theory” itself is not unproblematic of course, for it has a range of meanings when comparing its usage in the natural and social sciences—which is not surprising and not necessarily an issue given the purpose and domains of the different disciplines—but in education it is found to be especially ill-defined and often contradictory, if not outright misused (see Thomas, 1997). Likewise in science education the conception and usage of “theory” is quite varied, and it is better to speak of theory in two senses, as “theory lenses” or “theoretical frameworks” as normally applied to conventional research (Abd-El-Khalick and Akerson, 2007). (But, as mentioned, there is little to no direct reference here to educational theory). Even this given conception, though, is of a different kind and much more narrow or “lower level” from the sense I have in mind—that is, its conception as a “grand” theory of education and its link both to the philosophy of education and curriculum studies. A typical (albeit older) example is Shymansky and Kyle (1992, pp. 760-1). In discussing how to re-think curriculum research and practice they can only identify “two theoretical frameworks” which “appeal as being suitable for research on science curriculum” (p.761), being those of “radical constructivism” and “knowledge constitutive interests” (the latter referring to Habermasian ideas of knowledge and interests). Yet neither of these is in any way adequate as a meta-theory of education for the discipline, since the former is confined to questioning the epistemologies of science, the teacher and learner,\textsuperscript{55} while the latter is confined to examining the nature of three different types of knowledge (technical, practical, emancipatory) in relation to helping ascertain the appropriate social project of schools—yet it should seem clear what is first required is to specify one’s educational theory as a prerequisite to address and answer these kinds of issues and problems.

\textsuperscript{54} Egan asserts in fact that the weight of theory goes all the way down, because “every consideration relating to education—whether the organization of furniture in the classroom or matters of local policymaking, so far as these are educational rather than socializing matters—must be derived from an educational theory. That is, there can be no such thing in education as distinct lower-level theories—whether of classroom design or instruction or motivation or whatever—but only general, comprehensive educational theories with either implications for [such] things or direct claims about such things ...” (1983, p.123). Alternatively, Hirst (1966) had argued against the view of education as an autonomous discipline.

\textsuperscript{55} This is to critique the theory on educational grounds. It has of course been vigorously critiqued on philosophical and epistemic grounds (Phillips, 2000; Kelly, 1997). Abd-El-Khalick and Akerson (2007) further mention its critique on empirical grounds.
Fensham’s book (2004) *Defining an Identity*—where he canvasses the views of prominent science education researchers worldwide—offers another important look at the role of theory (Ch.7) within the science education community. He admits that the development of theory is a significant indicator of a discipline’s advance as a research field:

If the existence of theory and its development is a hallmark of a mature research field there is some evidence that the research in which the respondents have been engaged in science education has reached this point. On the other hand, the role that theory plays in the respondent’s remarks was so variable that it is not possible to attach this hallmark in a simple way to much of their research (p.101).

With that admission he acknowledges that the use of theory is constricted and there was little interest on the part of researchers to develop their theory of choice further. What is significant though, is the range of *borrowed* theories that the researchers have relied heavily upon, from social anthropology, ethnology and cultural theory to psychology, cognitive science (eg. information processing; schema restructuring) and philosophy of science (eg. conceptual change theory). Reliance upon psychology is clearly predominant, primarily Bruner, Gagne and Piaget in the 1960s and 70s and the role they played marking the shift against behaviourism.

Fensham also mentions the topic of “grand theory” (p.107). He writes that only one respondent had admitted to theorizing on this scale, namely the chemical educator Joseph Novak, who had published *The Theory of Education* (1977). This book however (as is familiar today), is based explicitly on the psychologist Ausubel’s quasi-neural theory of meaningful learning. Novak has today continued to hold to the value of this theory and the belief that “theories in science education would be developed that have predictive and explanatory power” (p.106), a belief that seems to closely align educational theory with theories in the natural sciences. It is admitted that Novak’s book and subsequent paper (1978) did help offer an important counter-theory in support of the growing dissatisfaction with the dominance of Piagetian theory arising in the late 1970s (although some science educators continue to hold neo-Piagetian views). With the growth of conceptual change and constructivist research in the 1980s and the influence of philosophy of science ideas, this dominance was gradually displaced in the science
community—but on the other hand, Erickson (2000) cautions there is much common
ground between Piaget and the newer constructivist theories.

We see that another important distinction that must be made clear is how the term
“theory” is used with respect to other disciplines. It is in the nature of an educational
meta-theory foremost understood as theory that the notion of “theory” as used in this
discipline (to prescribe a kind of educated person or mind) should be clearly
distinguished and not limited to a tighter, prior formulation of the term as commonly
applied in other fields—the natural or social sciences, philosophy of science or even in
those psychological schools who wish to define themselves exclusively as “scientific” or
empirical disciplines (e.g. behaviourism; Piagetian theory; neuro-psychology).\textsuperscript{56} It is to
the credit of the ongoing development of science education as an independent discipline
that some researchers have recognized this distinction, at least with respect to theories in
science: “A failure to consider this fundamental difference between the nature of
scientific theories and the theories of science education is damaging to science education”
(Gunston and White, 2000, p. 294).\textsuperscript{57} The distinction however, seems more difficult to
make out when researchers draw upon theories from other disciplines. An important

\textsuperscript{56} A fundamental difference is that such a theory is not empirically testable in practice (at least according
to some presently applied research conceptions and methods), which is not to imply it will have no
empirical consequences. See here Hirst (1966) and Driver (1997). One may speak loosely, for example,
about the “falsifiability” of such a theory if its methods do not contribute in large measure to the aim/ideal
sought, however, because of the complexity of educational phenomena even here caveats abound. Again
the problem is that as an independent discipline education must spell out a useful notion characteristic of
the discipline and not beholden to previously framed conceptions specific and useful in other fields, which
are hardly transferable. On the surface the magnitude of this difficulty for education should not be expected
to be of the same order, nor create the same dilemmas, as it has for “scientific psychology” which explicitly
seeks to emulate the natural sciences. Egan (1983, p.119) writes: “The study of education is [to be] engaged
in so that we may construct better educational programs, and prescribing how to construct such programs is
the function of educational theories. Such theories are clearly unlike theories in physics or psychology, and
we might well debate whether the differences are so great that the term “theory” should not be used to refer
to them.” He goes on to argue that the term serves an important purpose and, in any event, the question
should be decided on pragmatic grounds, and hence should be chosen.

\textsuperscript{57} Hirst (1966, p.40) had made this distinction decades earlier, but it bears repeating again: “Educational
theory is in the first place to be understood as the essential background to rational educational practice, not
as a limited would-be scientific pursuit.” He goes on to criticize those who would “fall back” on their
“scientific paradigm maintaining that the theory must be simply a collection of pieces of psychology.” Both
Hirst and Egan stress the normative character of such a theory. I should like to emphasize that from an
Aristotelian point of view (and I would like to interpret Hirst here accordingly) the fundamental difference
lies in the nature of the reasoning involved—phronesis (“practical discourse”) instead of episteme
(“knowledge that is organized for the pursuit of knowledge and the understanding of our experience”).
Originally I had thought to have discovered an implied recognition of this distinction in his paper but he
has admitted of late to having “failed” to acknowledge this in his earlier works (2008a, pp.119-120).
example is the paper by Norris and Kvernbekk (1997), and one of the few to address the vital subject of educational theories and their application in science education, although confined to constructivism (the typical subject when this topic is broached in the literature). They use the semantic notion of theory as discussed in epistemology and philosophy of science as a lens to analyze and critique the usefulness of the constructivist theory of science learning as developed by the late Rosalind Driver and her associates. This remarkable and original paper while offering insight into how goal-directed theories function and the problematic relation of any theory in the social sciences to practice (that the connection always remains an indirect one, through mediation of auxiliary hypotheses and by interpretations and judgments of practitioners), nonetheless bears inherent limitations because of their use of such a semantic conceptual lens, as Driver (1997) in response had pointed out. I would argue, along with Driver, that “normative goal-directed theories” as defined by the semantic notion of theories is not possible at the level of generalization of a meta-theory, although it may be possible at a lower level, and that the “analytical techniques used by [the authors] to analyze the theory actually distort the core features of the theory” (p.1007). Further, I would add one must be very attentive to the context when using such terms as “normative goal-directed theory”.

As discussed, any educational meta-theory must be both normative and goal-directed but not in the combined sense of the prior use of these terms in the semantic-epistemic conception, especially if it detracts from the explanatory power of the theory. Moreover, as I understand it even Driver’s useful constructivist account would itself serve at best as a sub-theory to a broader educational meta-theory, for it functions exclusively as a theory of learning and instruction but expressly not as a theory of either cognitive development (which at least the stage theory of Piaget and other neo-Piagetian theories have articulated; Niaz, 1993) or content selection.\footnote{Norris and Kvernbekk do not seem aware of this, nor is there any reference to philosophy of education.} And as Osborne (1996) has correctly pointed out the omission of these two latter important aspects (“when” and “what” to teach) must rule out any form of constructivism as a viable candidate for metatheory status, irrespective of the grand claims of some enthusiastic endorsers
One of the responsibilities of a philosophy of science education (PoSE) as I see it would be to better clarify the relationships between educational theories (especially metatheories) and theories in other disciplines, as to their nature, whether it is one of independence or inter-dependence. In other words, a philosophical appraisal of several domains, such as: conceptual clarification and the validity of borrowed ideas; the critical analysis of the models employed (range of usefulness); also the character, quality and significance of kinds of tests, etc., and hence the question of boundaries, applicability and relevance.

2.5. Why Does Science Education Require a Metatheory?
In having followed the discussion one could hope the merit of metatheory has become palpable: science education does not have one. The inconsistencies and incompatibilities in its major goals bear this out (Bybee and DeBoer, 1994), the confusion in the conceptions of science literacy (based on alternative “visions”) attests to it (Roberts, 2007), and the disputes (sometimes strident) over constructivism give witness to it (Matthews, 2000). It requires a metatheory for reasons comparable to what Aldridge et al. (1992, p. 684) claim is necessary for education: i) that “the purposes of a psychological theory are different from an educational theory”, thereto, ii) the implementation of such theories is usually problematic; and iii) the “relationship of development and learning [of science] is unique in educational settings”. These three reasons (which are inter-related) aim to detach education from psychology, and so may be considered as separation arguments. They go on to list another two, but these are based moreso on the actual inadequacy of the discipline itself—a curriculum-based argument and a grounding argument: iv) “education does not have a unifying metatheory which incorporates both curriculum development and assessment procedures”, and v) “education does not have a metatheoretical basis”. We will see later that Egan considers arguments i) to iii) as particularly forceful, especially since he holds that applications of disciplinary theories

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59 This would also hold true for conceptual change theory (CCT), which Abd-El-Khalick and Akerson, (2007, p.190) have pointed out is probably the only original “educational theory” (used in the restricted sense) so far explicitly developed by science educators.
60 Such a conversation can be considered an extension of one already discussing the difference between epistemology and psychology (Matthews, 2000; Kitchener, 1992; Duschl et al., 1990).
outside of education far too often do serious damage to it (2005a; 1983). Moreover, the fourth curriculum-based argument does not go far enough in its conception of curriculum: any useful curriculum must also seek to incorporate content and learning in correlation with the maturation of the learner at age-appropriate stages. Such a learner-based developmental theory that correlates maturity with curriculum, learning and assessment would truly qualify as a “unifying metatheory” and be exceptional. The question whether Egan’s metatheory qualifies will be addressed in the next section. If so, it has serious ramifications for how people can come to be “educated in science”, as to what that can mean, and thereto, possibly help ground science education as a discipline.

Psychology as a discipline is new, hardly more than 110 years old. Psychologists have generated, developed, or expanded at least four world views and multiple subtheories. Education has been around for centuries. We have no metatheory. We have no educational theories at all (Aldridge et al., 1992, p.687).

In writing that “we have no educational theories” I cannot imagine the authors should be taken to imply that educational theories have never existed or been proposed in the past. As mentioned, such theories go back at least as far as Plato (Republic; Laws) and Aristotle (Politics), but these were primarily philosophers, as were Locke (1693) and Rousseau (Emile, 1762). While the latter two were occasionally employed as private tutors (as was Aristotle to Alexander the Great), their foray into education was limited and they remained mainly outsiders, although Rousseau’s ideas or versions thereof (in progressivism) are spread widely, in various guises (Darling and Nordenbo, 2003). Plato and Aristotle can be considered both educational theorists and practitioners, given their establishment of the two famous ancient institutions of higher learning (the Academy and Lyceum, respectively). How far they attempted to actually incorporate their theoretical ideas into practice in those places is unknown, yet it does appear plausible that Plato considered his Academy as contributing to the development of a state-guardian class in Greece at the time. Be that as it may, the point here is not to judge the educational credentials of some well-known thinkers of the past, rather, to pronounce along with the
cited authors that for quite some time education has suffered from the characteristic lack of such theories formulated by and for those directly involved in educational studies. 61

Considering the current controversies about goals in science education (Bybee and DeBoer, 1994), one may be surprised to learn that even educational debates have a long history, for Aristotle records:

But we must not forget the question of what that education is to be, and how one ought to be educated. For in modern times there are opposing views about the task to be set, for there are no generally accepted assumptions about what the young should learn, either for virtue or for the best life; nor yet is it clear whether their education ought to be conducted with more concern for the intellect than for the character of the soul. (Politics, VIII ii: 1337a33; 1962/1981, p. 453)

I mention this here because it is remarkable to contemplate how his discussion mirrors the debate of values and aims that has steered science education since its inception in the 19th century. Consider if you will the conflicting meanings (post WW2) of science literacy 62—whether it is to be primarily understood as personal self-fulfillment (i.e. “virtue” as its own intrinsic worth), or for “critical citizenship” in a democracy (i.e. as instrumental worth; “the best life”: STS), or rather solely for development of “mind” per se, as mastery of subject-based formal knowledge and as a tool for developing inductive (later redefined as “critical”) reasoning (i.e. “intellect” development; science “processes”: Traditionalism), or finally, whether it should encompass foremost moral development when arguing “socio-scientific issues” (SSI) or “science education as/for socio-political activism” (i.e. “character of the soul”, always seen by Aristotle in terms of

61 This fact has not gone unnoticed, notably by Piaget in 1977 (quoted in Aldridge et al., 1992, p.685):
“The general problem is to understand why the vast array of educators now laboring throughout the entire world ... does not engender an elite of researchers capable of making pedagogy into a discipline, at once scientific and alive, that could take its rightful place among all those applied disciplines that draw upon both art and science.”

62 The term itself first came into use in the late 1950s. Initially broadly framed in terms of science, culture and society relationships, it soon came however to mean learning technical, subject-specific knowledge:
“This emphasis on disciplinary knowledge, separated from its everyday applications and intended to meet a perceived national need, marked a significant shift in science education in the post-war years. The broad study of science as a cultural force in preparation for informed and intelligent participation in a democratic society lost ground in the 1950s and 1960s to more sharply stated and more immediate practical aims” (DeBoer, 2000, p.588). By the 1980s the phrase had become commonplace: “Yet despite the problems of definition, by the 1980s scientific literacy had become the catchword of the science education community and the centerpiece of virtually all commission reports deplored the supposed sad state of science education” (Shamos, 1995, p.85).
socio-political activity). Note as well that the three fundamental goals underlying education (as elaborated above) can be identified here and roughly mapped onto the corresponding conceptions of literacy and, to some extent, onto existing school science curriculum paradigms. Some critical observers had thus come to the conclusion that already by the late 1980s the usefulness of the literacy concept had exhausted itself:

It was confusion over the differing connotations of scientific literacy, the attempt to subsume all under a common heading, from mastery of basic knowledge to national technological superiority, from science viewed as a cultural imperative to that of social responsibility, from science content to science attitude, that finally led to serious questioning of its real purpose. The goals were simply too fragmented and not accepted with universal enthusiasm by the science education community (Shamos, 1995, p.85; my italics).

Regardless of how one wishes to characterize it, I believe one can without much controversy state that “science literacy” nonetheless still remains (for good or ill) the prime goal or aim of science education\textsuperscript{63}, certainly in the English-speaking world but increasingly in other parts as well (Roberts, 2007; Jenkins, 1997)\textsuperscript{64}—although Shamos has insightfully argued that its common conception tied to citizenship is fundamentally flawed, that the community is chasing a utopia, that it continues to refuse to accept the grounds why it has failed in achieving it, and finally that many rationales typically put forth to justify it are a myth.\textsuperscript{65} In this sense the discipline has decided, no matter how contested, on its “why”, and to differing degrees also on the “what” and “when” (depending on the prior construal) —however, these are merely mechanical because the

\textsuperscript{63} The Standards documents in both America (AAAS, 1993) and Canada (Council of Ministers, 1997) make this explicit. Unlike in the U.S. the Canadian document has legislative force. Bybee and DeBoer (1994, p. 384) have concluded: “Scientific and technological literacy is the major purpose of K-12 science education. This purpose is for all students, not just for those destined for careers in science and engineering”. That science education should also be saddled with the added burden of trying to specify, teach and aim at “technological” literacy seems rather odd considering the debate that still revolves around “scientific” literacy. Unfortunately both terms are too often conflated whereas in some countries they are tied to separate courses (Layton, 1993). And certainly while all parties may agree that science literacy is for all students, that slogan explains little, neither does it consider the fact that many students have no interest in science, nor does it contribute to resolving the quandary concerning criteria for content selection (Fensham, 2000).

\textsuperscript{64} Roberts (2007) comprehensive review of the term (also noting the occasional conflation of scientific and technological literacy) illustrates its increasing reference in handbooks and at science education research conferences worldwide.

\textsuperscript{65} Most importantly, his demolition of the two standard rationalizations of the common literacy conception—which Fensham (2002) acknowledges and terms the pragmatic and democratic arguments—effectively serves to undermine what has become the grounding assumptions of the STS literacy rationales.
“why” has nowhere been embedded within an educational metatheory (as argued previously). Further, it seems clear that some advocates construe the literacy aim to be a kind of person (the wider notion: the images of either the professional scientist or the active citizen), whereas others construe it to be primarily a kind of mind (the narrower notion). Hence, the desired or constructed curriculum is dependent in large measure upon one’s prior paradigmatic and incommensurate commitments (traditional; multi-culturalist; HPS; STS; SSI; “socio-political action”, etc.) based on the background goal. It thus serves more as slogan than as definition. I submit that as long as this state of affairs persists the controversy surrounding scientific literacy is not resolvable—nothing less than a scandal. We have a situation here where a discipline cannot agree on the most fundamental purpose and goal of its educational endeavor (Roberts, 2007; DeBoer, 2000; Shamos, 1995)66

One can therefore conclude, given this consistent mode of discourse about “science literacy”, that the community is placed before one of three choices:

• **exclusivist** option: one chooses either an already given or hoped for curricular paradigm; this could be the knowledge-based, specialist “Vision I” literacy conception (the given: traditionalism) or, at the other end of the spectrum, opting for an “extreme” form of “Vision II” by redefining literacy as “collective praxis”, such as the (hoped for) image held by Roth and Barton (2004), according to Roberts (2007, p.769).

• **inclusivist** option: one agrees instead to hold fast to as many conflicting meanings as possible. Along with DeBoer (2000) one simply accepts the term stands for “a broad and functional understanding of science for general education purposes” (p.594) and “because its parameters are so broad, there is no way to say when it has been achieved. There can be no test of scientific literacy because there is no body of

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66 The various Standards documents have sought to achieve a kind of ‘balance’ between these goals all-the-while feigning a consensus that is non-existent. And as stated earlier, they run at cross-purposes according to Egan’s critique (see DeBoer (2000) for a list of nine competing goals). I would add, to square intrinsic aims (science for personal development, for aesthetic appreciation and cultural literacy of the value of science) with extrinsic utilitarian aims (socialization) is most difficult and probably unworkable since it is to square a deontologic with a teleologic, to seek something for its own good versus to seek it as utility for another end. We may seek to do this with aspects of our lives, but to attempt to establish curriculum and goals on these conflicting principles, especially in the confines of a real school schedule and practice seems destined to fail. Hence, the Standards documents taken alone seem to be engineering their probable curricular gridlock as a working project and attempted practical resolution in classrooms of the science literacy debacle (Roberts, 2007; Fensham, 2000; Rudolph, 2000; Shamos, 1995).
knowledge that can legitimately define it. To create one is to create an illusion" (p.597). Rather, only specific goals can be achieved in a piecemeal fashion, where his historically identified nine different conceptions are chosen as in a smorgasbord, attentive to the context of school culture and society wishes, and where "schools and teachers need to set their priorities" (ibid.). With this option, divergence is chosen. It is then assumed that "consensus about one definition throughout the worldwide science education community is a goal not worth chasing" (Roberts, 2007, p.736).

*abandonment* option: one chooses to reject the term as both useless and meaningless for educational purposes, along with Solomon (1999) and Shamos (1995).

Option two although seemingly attractive on the surface does not seem to me to be viable, and one can imagine numerous problems associated with it. Just mentioning one, it assumes a degree of autonomy for schools and teachers which they generally lack, and which in the climate of "accountability" and standardized testing and under the influence of powerful outside social groups would seem to check their ability to make the kind of choices DeBoer would like. A reversion to option one would in all likelihood result, namely, the default traditionalist position. In any case, if an educational metatheory is to be of service to science education it must also acknowledge and address these options in the deadlock. It may also put into question the assumptions and scope of the discussion and even the entire character of the discourse which has heretofore been conducted.

Now some may wish to argue that such a plurality of meanings is not necessarily a bad thing and, on the contrary, indicates the health and "maturity" of the discipline,

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67 Long a popular advocate of the STS conception of literacy, Joan Solomon would now drop this word for what she calls "scientific culture". Shamos alternatively would substitute science "literacy" with "awareness". He does describe three kinds of science literacy, however, those of "cultural", "functional" and "true", all of which Roberts nonetheless locates in the "vision I" category.

68 The example of what has happened with the NSES document during implementation efforts in California supports this assertion (Bianchini and Kelly, 2003).

69 Option two would also seem to allow for a two-tiered kind of science education system (along with its respective science literacy conception): allowing a school to choose a type of "vision I" for the science-bound student (traditionalism) and another stream for the general non-science student with its "vision II" focus on either cultural or technological literacy or social action—chosen as desired. Shamos has suggested something along these lines as a way to resolve the impasse. Roberts (p.741) admits that although "this approach is at odds with the majority of the science education community" it is "a stark and forthright acknowledgement" the community must "somehow resolve the problems associated with educating two very different student groups (at least two)".

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where typically a variety of viewpoints are allowed to be expressed, criticized and defended, and where a diversity of research programs are in play. “It might be argued that science educators collectively do not see curricular reform as a unified ‘project’ at any level. Nor should they, some might say: there is merit in diversity” (Donnelly, 2004, p.764). It was in large part in reaction against the perceived trend of an all-embracing “one-theory-view” of constructivism within the science education research community that several authors responded that “consensus” can be an unattractive and debilitating quality. Because “‘consensus’ is at most a transitory feature of scientific progress both in science and education” (Niaz et al., 2003, p.790), the authors reasoned instead that it was the critical appraisal of competing research programs which had facilitated what can be called “progressive transitions” in the discipline. Some may therefore protest that my suggestion for the need of consensus around “metatheory” may similarly represent a regressive rather than a progressive move for the community.

While I am in general agreement with the view expressed by the above authors regarding constructivism, I would still like to point out a few things: first, that most kinds of research programs are not usually informed by any sort of high-level educational theory; secondly, that debates concerning constructivism occur at a lower level with regard to learning theories (but where the values and principles of an educational meta-theory as can impact the discussion is missing), and thirdly, that debates concerning issues of goals and science literacy must be transported to and answered on a metatheoretical level. Surely such a discourse is long overdue (Anderson, 1992). There is no doubt that diversity is to be welcomed and “while accepting the partial legitimacy of this view”, I argue, along with Donnelly (2004, p.764), “[we] yet maintain that curricular change in science is, to a degree which is counterproductive, an inchoate search for rationales, justifications, and specific innovations in the face of perceived deficiencies”. Certainly one must always be vigilant against any kind of “groupthink”—as was perhaps threatened by constructivism and which the authors correctly raised concerns about—that talk of metatheory usually brings with it. But science education has shown itself time and again to be vulnerable to an extraordinary degree with its reliance on extra-disciplinary metatheories (psychological and economic), on the one hand, and has not managed to develop any explicit educational metatheories of its own, on the other. Moreover, I
should like to point out that especially with respect to the natural sciences (a mirror I likewise hold up for it is favored by too many science educators when formulating arguments and making comparisons for their discipline), even the physicist Lee Smolin, in his trenchant critique of the conceptual and sociological problems plaguing contemporary theoretical physics, still insists that in order for a community to thrive it requires not only a diversity of research programmes and contrary ideas, but equally at times “we can say that science progresses when scientists reach consensus on a question” (2007, p.295). The obvious inference being, based on an argument of parallelism, that this should hold as well for our educational community.

At this stage in the discussion, and not by accident, a different sort of objection concerning the assumed need of “metatheory”—and indeed “theory” in general—could also be raised, but on different grounds, being the question of the relationship between theory and practice. What is of interest for education, so goes the oft-repeated stance, is not a matter for theory (at best it is only narrowly concerned with theory) because the discipline is predominately concerned with practice—this, as it turns out, is a basic critical rejoinder that has earlier come to the fore in associated literature. Things have certainly not been quiet regarding the relation of theory to practice in the social sciences, in curriculum studies or the philosophy of education; still, here is not the place to indulge an elaborate discussion of the issues involved (Blake et al., 2003; Thomas, 1997; Hiley et al., 1991). Nevertheless, a few comments seem unavoidable. With the attack and undermining of foundationalism, and hence the rejection of the claim of the universal validity of theory, there are those who have sought at one extreme to solve the theory-practice problem by hoping to considerably diminish the role if not dispose of theory altogether—at whatever level. They have been encouraged in this regard from several quarters, both critical and practical: a return to Aristotle and his ideas of habituation and phronesis; the hermeneutic tradition; Feyerabend’s ‘anarchistic’ criticisms of the philosophy of science; Lyotard’s attack on ‘totalizing metanarrative’; as well as a revival of interest in Deweyan pragmatism. There has come the general realization of the considerable difficulties entailed when applying any theory in the social sciences to
practice in useful ways.\textsuperscript{70} This is the most radical and strongest position and, if successfully challenged, carries away the weaker ones in tow. To meet this challenge five counterpoints will be brought to bear.

The first point to be made here is that "theory" can and has survived the collapse of foundationalism and such a wholesale and radical rejection is therefore not warranted. For already with Hegel "theory" was taken as systematic without being construed as foundationalist (Rockmore, 2004). Secondly, the need for metatheory must be maintained as a critical bulwark against several alarming tendencies, of which I cite two: an academic one which tends to cognitive and moral relativism, only partly as a result of the "linguistic turn" (Rorty) after the collapse of foundationalism, but more commonly under the strong influence of a misguided anti-science attack (Gross, Levitt and Lewis, 1996).

For science education to ignore educational philosophy and theory is to leave it directly exposed and vulnerable to those who would seek to reshape the discipline by importing theories based on radical social constructivist views and epistemological-relativist perspectives (Weaver et al., 2001; Loving, 1997). An example here is the attempt to use ideas from Lyotard to transform the discipline (Schulz, 2007). The other tendency is socio-economically driven, and described as the new "managerialism" with its emphasis on "accountability", testing and proper socialization, required, so it is argued, in order for students to navigate the emerging global techno-economy. This kind of socialization argument, though, is only a more recent manifestation of one that has pursued science education for decades (as discussed earlier), and by taking the form of an extreme reduction to educational instrumentalism (economic utility; Jenkins, 1997; Apple, 1992) can only be effectively challenged on the grounds of an alternative vision offered by a metatheory.

A third argument is the fact that all perceptions and practice are unavoidably "theory-laden", a phrase brought to popular parlance because of the developments in the philosophy of science, a fact well-known to those in the HPS movement. The position that science education requires a high-level theory to inform its practice and clarify its

\textsuperscript{70} "Increasingly it has been claimed that education is itself practice with its own internal rationality, mediated by tradition, which does not need to be informed by external theory from the "disciplines of education", including philosophical value-theory, and that practical action should not be conceived on a technicist model of the application of high-level generalizations to particular cases" (Blake et al., 2003, p.7).
aims is basically to acknowledge that “theory” should “come to the surface” and be explicitly recognized. Otherwise one inevitably runs the risk of using some theory of which one is not cognizant, but which nonetheless guides practice and covertly channels the discipline—which seems to be the ongoing case with the field and its buckling under to the socialization imperative, itself often shaped by either economic or social-utilitarian philosophical metatheories (e.g. Dewey). This equally and markedly holds true at the local classroom level. Bruner (1996, p.161) has stressed that there already exists a folk psychology and folk pedagogy among both teachers and learners, and that it is their “folk theories” which engage the practice of teaching and learning, and not necessarily in the best interest of the learner, that the pedagogical theorist must in some way also take into consideration.  

In short, to assume “theory” can be avoided is deceptive.

This fact is linked to the fourth: science education in particular and education in general (let me repeat) tend to default to external disciplinary theories according to the newly discovered maxim that “educational development abhors a theoretical vacuum”. It is commonplace to defer to metatheories in psychology but even here educators as a rule often disagree which sub-theories of development, learning or motivation to apply (Bruning et al., 1995). Egan has shown by a series of cogent and careful arguments that when education defers to metatheories in psychology whether (as examples), directly via behaviorism or Piagetian theory (2005a; 1983), or indirectly via progressivism (2002), the debasement of practice and a wide-ranging impoverishment of the field must necessarily result.  

I suspect science educators’ mix-and-match approach with regard to,

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71 “Stated boldly, the emerging thesis is that educational practices in classrooms are premised on a set of folk beliefs about learners’ minds, some of which may have worked advertently toward or inadvertently against the child’s own welfare” (Bruner, 1996, p.163).

72 This censure is meant to include authors such as Thomas (1997) who when criticizing “grand theory” (he mentions Piaget, Chomsky and Habermas) as a “totalizing discourse” constraining creativity and thought would opt instead for “ad hocery”, for practitioners reliance on “reflective thinking” and “craft knowledge” learned in situ. Although these are undoubtedly necessary, they are hardly sufficient.

73 He argues: “psychology has generated much knowledge that is properly of interest to education. Knowledge by itself is mute, however; it is made articulate by being organized into a theory . . . Knowledge about the psyche, about learning, development, motivation, or whatever, becomes psychologically articulate when organized by a psychological theory. The same knowledge may become educationally articulate only by being organized within an educational theory. This is not, I think, a trivial point. It means that apart from an educational theory no knowledge and no theory have educational implications. Even knowledge about constraints of our nature becomes educationally useful only when it has become incorporated within an educational theory . . . ” (1983, pp.122-3). Hence, the controversial conclusion: “psychological theories at present have no implications for education” (p.125).
say, psychology, "science studies" or, lately, language theory, is predominately dictated by *conditions* of immediate practice (including classroom culture) and not informed by any sort of educational theory or a more encompassing *philosophy* behind their instruction—the latter necessity Scheffler (1970) had stressed some time ago. The popularity and conflicting strands of constructivism itself bears witness to this (Geelan, 1997). Such a complex, incoherent and chaotic state of affairs I cannot imagine will contribute moving the field towards a more academically grounded or "mature" discipline (Kyle *et al*., 1992).

Hence, *lastly*, a metatheory (as previously mentioned) is required to advance the field into a suitable discipline standing on its own merits (as Piaget had opined could be termed a "science of education", yet Egan would fervently eschew such a notion, as no doubt Dewey would have done). It is needed to "develop and coordinate curricula congruent with assessment procedures" and helps decide "what to teach, when to teach, and how to teach." Barring this, "we will continually take the bandwagon or pendulum-swinging paradigm as our process and adopt the next psychological theory that comes along" (Aldridge *et al*., 1992, p. 686). It would also bring science education back into the fold of how "theory" has come to be positively reappraised again in the philosophy of education, so that it may truly "engage in explorations of what [science] education might be or might become: a task which grows more compelling as the "politics of the obvious" grow more oppressive. This is the kind of thing that Plato, Rousseau and Dewey are engaged in on a grand scale" (Blake *et al*., 2003, p. 15).

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*Some may object here and argue that science education (and education in general for that matter), can be considered a mere "field of interest" upon which other disciplines have rightful bearing, and thus should *not* be considered a discipline in its own right. Hence, the argument has been ignored why education when being conceptualized primarily as a field of *practice* that it, at best, could rightfully accept an amalgam of theories from other disciplines, or use different theories for different purposes, such as ethical theories to define the 'why', and social and psychological sciences for the 'what', 'when', etc. This position ignores both the logical and historical reasons why there are separate disciplines. Disciplinary theories frame the kinds of questions and answers relevant to them: using a psychological theory to guide your questions will get you psychological answers; if you use a theory from sociology, you get sociological answers, etc. Disciplines (surely) are basically imprecise methodologies for answering certain kinds of questions. Even if education is only a "field of interest", you need questions, methods, and answers appropriate to that field of interest. The record of ignoring the distinctiveness of education in research does not give grounds for confidence that this is serving us well. Calling education a "field of interest" does not prevent one forming a "high level theory" about it—as long as that theory is appropriate to the nature of the phenomenon, and can guide one into asking appropriate educational questions, and suggesting possible answers, about the phenomena.*
2.6. Summary

This chapter has so far attempted to ascertain why science educational reform has been so intractable a problem for so long in its historical development. The “conventional wisdom” still seems to hold that, ideally, a proper scientific mind should be a probable, if not an inevitable result of our contemporary educational system, preoccupied as it is with the mastery of textbook-based formal knowledge (content and processes), stylized laboratory work, and with instruction and knowledge organized according to the disciplinary structure of the separate sciences. Yet in the past several decades numerous studies in science education research in general, and physics education (PER) and chemical education research (CER) in particular, have established that all three of these components are fundamentally inadequate to meet this outcome. That is, the curriculum remains too narrowly specialized, school laboratory work distorts the image of actual scientific inquiry and instruction has chiefly overlooked the psychology and contexts of learning, including accommodating students’ prior conceptions which create considerable barriers to comprehending complex and abstract scientific schemes.

Although the conventional wisdom is identified as an immediate obstacle to reforms, as an established school educational paradigm it was linked to a broader impediment located at the nexus of a confluence of several factors: first, competing school-based “paradigms” with their own largely exclusivist conceptions of scientific literacy. These are themselves strongly influenced by social groups and their educational “ideologies” (both external and internal to the community) including several science education-based research programmes; secondly, the ongoing neglect of generating discipline-specific educational theories (not restricted to learning theories, and which could help clarify curriculum and goals), in conjunction with, thirdly, the prevalent disregard of philosophy of education. Crisis-talk has commonly tended to mask the competing interests of diverse social groups, including the lack of consensus over “science literacy” and division within science education research groups. It has been inferred that the fundamental reason why there continues to be inherent difficulties for prioritizing the main goals in science education is reflective of the reality that three essential aims exist that underlie general education which themselves undercut each other’s potential and which science educational reform history bears witness to but which
it has not openly acknowledged. Attempts at “balancing goals” were judged ineffective if not illusory.

To help resolve the reform and science literacy quandary it has been suggested that the science education research field requires a partial conceptual and theoretical re-orientation towards the neglected field of philosophy of education, and thereto, that a new theoretical-based research field should be broached entitled “philosophy of science education” (somewhat along lines as initiated by Paul Ernest and his work outlined for a “philosophy of mathematics education”). To that end it has been further advised that an educational metatheory should be developed which could help ground science education as an independent discipline, help distance it from various metatheories in psychology, and finally help it better navigate the demands of group interests with respect to instrumentalizing the educational endeavor as a desired socio-utilitarian project. Viewpoints that argued that entertaining a metatheory for the discipline could be counter-productive, or holding the position because education was primarily concerned with practice, “theory” was either superfluous or debilitating, were rejected based on five counter-arguments. In addition, it was argued that a metatheory could offer a possible solution to the “three-options” deadlock science education is currently embroiled within regarding the conceptions of scientific literacy by offering an educational discourse coming from an entirely unusual but progressive perspective.

The next chapter will compare educational traditions in the Anglo-American world with the Central and Northern European region, known to employ its own exceptional metatheory (Bildung), in order to contrast these with Egan’s ideas and to better help locate the place of a philosophy of science education with respect to Shulman’s concept of Pedagogical Content Knowledge (PCK) and enhancing science teachers’ epistemology. Egan’s cultural-linguistic version will be introduced to the research community as a potentially useful metatheory while providing examples of its use for reforming science education.
CHAPTER THREE: Philosophy of Science Education and Kieran Egan’s Educational Metatheory

“Engaging the imagination is not a sugar-coated adjunct to learning; it is the very heart of learning.” —Kieran Egan

3.1. Locating philosophy of science education: Bildung, Educational Metatheory, and Pedagogical Content Knowledge (PCK)

The central importance of metatheory discussed so far raises the related question as to whether or not educational systems in other countries have also considered the need of such theories for their use as a coherent approach to the problems associated with curriculum aims and implementation. This has indeed been the case with the Bildung-centered Didaktik tradition of central and northern Europe. It seems to me quite clear that the Bildung tradition functions as a metatheory of education in ways very similar to Egan’s ideas and intentions and can thus serve as a useful parallel theory for comparison, but especially for contrast to the common Anglo-American “Curriculum” tradition prevalent in the English speaking nations. What is of more immediate interest to me will be not only sketching out the contrasts but in locating the position and value of a philosophy of science education among these theories and traditions, especially in light of some very recent awareness of these differences in science education research.

In the 1990s groups of scholars on both sides of the Atlantic had already begun a cooperative project to better understand similarities and differences between the two major educational traditions. This dialogue manifested itself in a special edition of the Journal of Curriculum Studies in 1995 (no.1, vol. 27) and in a series of books, of which I mention Didaktik and/or Curriculum. An international dialogue (1998), edited by Bjørg Gundem and Stephan Hopmann, and the essay review of books by Vásquez-Levy (2002). Fensham (2004, p.146) states that the catalyst for this dialogue can be traced back to Lee Shulman’s (1987) original discussion of Pedagogical Content Knowledge (PCK). It was the recognition that the problematizing of subject content for its appropriate integration in pedagogy “attracted the interest of those in the Didaktik tradition for whom subject content had always been a central issue and integral approach to research.”
What also became apparent during the dialogue were the obstacles encountered with foreign concepts like "Didaktik" and "Bildung". The closest term to the former is "didactics" in the English speaking world, but this has a separate and primarily a pejorative connotation\textsuperscript{75}, whereas the latter term has no equivalent at all and bears difficulties in translation. Bildung, a concept which has developed out of the 19\textsuperscript{th} century German romantic movement, encompasses an array of ideas often employed in the English-speaking world when one focuses on the personal development of the individual and coming-of-age, the cultivation of intellectual and moral powers through subject matter to advance critical thinking and enhance the state of freedom for individuals and society, or viewing the general role of education to foster "an ideal of self-determination, the formation of character, or exercise of autonomy, reason and independence" (Vásquez-Levy, 2002, p.118). All these labels and qualities are intrinsic to the concept:

\textit{Bildung} embodies a double process of inner-developing and outer enveloping, what Germans call \textit{Allgemeinbildung} and \textit{Ausbildung}. On the one hand, the concept \textit{Bildung} describes how the strengths and talents of the person emerge, a development of the individual; on the other, \textit{Bildung} also characterizes how the individual's society uses his or her manifest strengths and talents, a 'social' enveloping of the individual (ibid).

On this formulation, one quickly recognizes the link with the 'humanistic tradition' of liberal education mentioned earlier as one of the three vital goals behind the purposes of science education. Given this interpretation one could in fairness associate the values of the \textit{Bildung} tradition with two prevalent "curriculum ideologies" in American education as identified by Eisner (1992), being "rational humanism" and the 'personal' stream within progressivism.\textsuperscript{76} It should be additionally mentioned here that Gadamer (1960/1975) takes \textit{Bildung} to be one of four fundamental guiding concepts (next to \textit{Sensus Communis}, judgment, and taste) that characterize the significance of the

\textsuperscript{75} "The word \textit{Didaktik} is the semiotic indicator of this discontinuity of conversation and, accordingly, of unshared appreciation of each group's work. What is clearly valued as a noun by one group has a derogatory meaning for the other as the adjective, \textit{didactic}, with its association in English with transmissive, instructional teaching" (Fensham, 2004, p.145).

\textsuperscript{76} Eisner (following Cremin) identifies two related but separate streams within progressivism, one "rooted in the nature of human experience and the development of intelligence ['growth'], the other in social reform" (1992, p.311); the first which emphasized the personal the other the political, although Eisner admits that Dewey himself would never have allowed for such a separation between personal and political.
humanist tradition for the Humanities (Geisteswissenschaften) and which therefore clearly distinguishes them from the so-called ‘method’ and disciplines of the Natural Sciences. Gadamer presents an elaborate discussion of the concept (including the roots of the idea and its conversation in Humboldt, Herder and Hegel), which are steeped in Rousseauian notions of self-formation, but which also later came to emphasize the role played by culture in this process, in particular Herder’s linguistic-cultural re-interpretation as “rising up of humanity through culture” (p.9). Rousseau’s influence weighed heavily on Goethe’s and Schiller’s views on education and the Romantics in general, and the further expansion of the self-formation idea by Herder, according to the Canadian philosopher Charles Taylor (1991), provided necessary contributions to the modern notion of the self as unique and authentic.77

With the idea of Bildung just described one may even so come straight away to identify some serious difficulties with the conception. The first point of issue is that Bildung appears as to be caught in a paradox, being defined as both means and ends, as the process of learning and personal growth as well as the final aim at which such growth or education itself terminates; between becoming educated and being educated (Gebildet). It shares this paradox with the ancient Greek conception of education as paideia as it developed in late Hellenism78. This should not be entirely surprising since German classicism relied heavily on the ideals of the Greeks and saw in paideia79 a useful analog. (Other parallels can be drawn today: Eisner identifies the “paideia project” of Adler (1983) as another example of curricular “rational humanism”). Secondly, Bildung was initially taken as inclusive of education for the state, but not as mere means

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77 In this way the essence of the ideas behind the Bildung conception in having become partially detached from the given educational traditions of Germany-Scandinavia, nonetheless became part of the wider philosophical-psychological discourse of the West.

78 “From the days of Socrates its meaning was systematically ambiguous, denoting as it did both “culture of the mind” or “civilized life” and the influences, processes, and techniques for the making of a man. In Hellenistic times, by a subtle extension of meaning, paideia came to refer to the results of educational effort rather than the means for achieving the end of education—the whole or complete man, an ideal toward which one might strive but never completely attain except through life-long endeavor” (Lucas, 1972, p.95).

79 Paideia comes from the Greek root words pois, paidos, the upbringing of the child. It became latinized by Cicero to humanitas, to signify the education common to all human beings which was transferred by language (literacy) and culture. Here, too, it had strong ethical connotations (areté, virtue). By the time of the Renaissance this interpretation was recovered, although it meant originally the specialized study of the classical Greek and Latin authors of the newly revised curriculum studia humanitatis in the Arts faculty. The original Greek root words are still found in our words pedagogy and pediatrics.
to that end, rather self-realization was taken to be an end unto itself, and where the state could serve as the means (Beiser, 1998). Yet an inherent tension arises here between self-realization (Rousseau) and the socializing demands of citizenship (including perhaps the wishes or commands of the state), as was sketched in chapter two with respect to Egan’s critique of these two essentially incompatible educational ideas. Vásquez-Levy in her Essay does not recognize the tension(s) when she writes:

This means that, through education, human beings are gradually opened to and connected with the world both as a historical process and as a natural and social environment. Education prepares us to participate as responsible citizens in the polis, the political and social order, so that we have some control over our own destiny with others. This approach is certainly what Socrates had in mind: the telos of education is free citizenship ... Thus, Bildung is the process of developing a critical consciousness and of character-formation, self-discovery, ... an engagement with questions of truth, value and meaning. The education of individuals is, therefore, a recapitulation of the cultural development of the world and the practice of freedom and work towards higher liberation (2002, pp.118-119). 80

This encompassing description of Bildung given above, moreover, goes even further, and appears to ascribe to this idea an amalgam of mismatched educational ideas, counting Rousseau, the Platonic knowledge-based project, as well as (using Eisner’s 1985 terms) both social adaptation and social reconstruction—the last two without a doubt mutually contradictory. It seems the conception (taken in its widest sense) is burdened by too many demands, even encumbered by incompatible ideas. But in actual practice choices must be made when decisions about curriculum orientations are considered; it is then no coincidence that when criticisms of the Bildung paradigm arose from those within Critical Theory (of the Frankfurt school) starting in the 1950s/60s, we find them targeting the differing aspects of its interpretation as manifested in schools: Adorno at first arguing that the notion had been “stripped of its normative content, its relation to a good and just life” with its critical, emancipatory edge questioning societal rules and expectations, for a shallow adaptation of capitalist norms and competence to function in the social order (Blake and Masschelein, 2003, p.40); afterward, other adherents of the School closer to our time had even come to impugn “the modernist ideal

80 Interesting the reference here to “recapitulation” of cultural development, for as discussed shortly, Egan’s metatheory also foregrounds a recapitulation thesis but shifts the emphasis towards a Vygotskian notion of linguistic, cultural-based cognitive tools.
of authenticity and questioned the limits of autonomy" (Blake et al., 2003, p.44). It hardly surprises today that this paradigm has come to suffer from attacks similar to ones which postmodernists have leveled at the Enlightenment tradition, those that have come to question the entire notion of the induction of children into a cultural tradition, one "which conceived this enculturated maturation as a form of emancipation" (Blake et al., 2003, p.9), and one which placed a heavy stress on the role of reason and rationality in the process. What is of issue here, however, is that Adorno's complaint can be taken as representative of the tensions between the "social adaptation" conception and a knowledge-focused Platonic-type tradition vying for dominance in the implementation of the Bildung interpretation, while the later critiques have put in doubt the essence of Rousseauian child-centered self-determination at the very core of the paradigm (to be replaced by a theoretical focus on education for "social reconstruction" purposes).

My digression on analyzing the conception of, and problems attached to, the Bildung paradigm serves a three-fold purpose. Besides the usefulness in clarifying the idea itself for an audience unfamiliar with the concept, was the chief objective to illustrate that Bildung as an overarching conception of the educational endeavor has by no means escaped the tensions and incompatibilities associated with the three fundamental ideas underlying general education as discussed earlier; on the contrary, these inconsistencies appear to be inherent to its inception and interpretation, of what it means and how it is to be implemented, and this in doubt mostly due to its Rousseauian pedigree. This brings us to the second purpose, the comparison of this tradition with the

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81 "To the Enlightenment ideals of transparency, autonomy, and authenticity, both Marx and Freud in their different ways counterposed the actual delusions fostered by alienation, anomie, and fetish—psychological failings constituting false consciousness both of society and self" (Blake and Masschelein, 2003, p.44). These criticisms have grafted Critical Theory with a predominant negativism towards society and education, even characterized as a form of utopian pessimism, Habermas being the exception. This charge though does not seem as appropriate for the associated "critical pedagogy" of Friege, Apple and Giroux. Yet even this American "curriculum ideology" as Eisner (1992) argues, has remained an academic protest movement with little to no effect on U.S. school systems.

82 Such a curricular ideology suffers from two serious failings: it rarely defines the new social utopia aimed at following the hoped-for "social reconstruction" (other than suggesting vague moral values, such as "true equality" or "non-colonialist"), and it conceives of educational practice in purely instrumentalist terms: "it has not questioned the very concept of educational praxis itself but conceived it as an instrument for liberation or repression. Educational praxis still receives its meaning from the goal or end at which it should aim, here conceived as a utopia." Worse, it is thus ensnared in the very problematic common to school education being run on a technicist model: "It thus remains itself subject to the same instrumentalist logic that it deprecates at the heart of the capitalist system" (Blake & Masschelein, 2003, p.50).
better-known Anglo-American “Curriculum” tradition. On many levels, the two traditions form a stark contrast, but as Reid (2003) has commented the dialogue between the two camps had been furthered by a mutual recognition of the apparent strengths of the other based on the perceived lack or weakness in their own. Yet this too, seems to me, to surface once again the incompleteness of the two traditions with respect to the three underlying educational ideas, because the advocates of each respective tradition have come to cherish that one fundamental idea seen as missing in their own educational project but alive in the other.

For example, in northern Europe, especially Scandinavia, there has been a revival of interest in Dewey’s ideas of schooling as a form of socialization into “differentiated democracy” and hence, coming to grips with the paradoxes of the aims of education which American education has already wrestled with for a century: “how can notions of utility be accommodated to the traditions of liberal education? How can authority in curriculum matters co-exist with a diverse population, not all of whom would see themselves as sharing a common cultural heritage? How can a common curriculum be made accessible to all students ...?” (p.22). On the U.S. side, especially during and after the Reagan years and the concern for establishing national standards of academic excellence due to anxieties about global competitiveness, has come an admiration for the Bildung/Didaktik ability “at maintaining coherence, at fostering achievement in the disciplines, and at retaining public confidence in standards of performance” (p.23). In other words, what the U.S. admired about the Didaktik tradition was its accomplishment at “academic rationalism” (Eisner)—or the Platonic-academic program—while the Europeans admired the American pragmatic approach using schools for fostering socialization of its student population in a multi-cultural context. Once more one notices the recycling of competing ideas not only as a recurring problem for science education but spanning two very different educational traditions. While there certainly is a willingness to learn and adjust one’s tradition in light of the other, there seems to be (as of yet) little appreciation of the impasse provoked by the educational projects of both.

We now come to the third purpose of the contrast which is to demonstrate how the advantages of the Didaktik tradition over the “Curriculum” tradition, also discussed in some latest science education research circles (mostly in Fensham’s (2004) Identity
book), offers insight into positioning a philosophy of science education and Egan’s own metatheory. Both Vásquez-Levy (2002), speaking generally about education, and Fensham (2004, ch.10), specifically addressing science education reform, admit the advantages of the Bildung paradigm over the standard Anglo-American “Curriculum” in allowing for: i) a coherent theoretical approach to curriculum design and implementation in so far as it serves as an educational criterion to assess subject content; thereto, and related to it, ii) in problematizing content for the learner, it places more emphasis on teacher autonomy and pedagogical knowledge to assess content for educational aims and purposes, and hence, forces them to wrestle with the nature and significance of the subject/discipline as consequent to improving their pedagogy and how pupils can/should learn the content in question.

When comparing the new 1994 system-wide documents for science curriculum reform in Norway and Australia, Fensham (2004) comments on the “stark and striking difference” between the two, and how the Bildung idea (as a metatheory) in Norway affects the rationale of education and steers the curriculum (Table 10.1, p.151): “In the one, the maturing young person is the purpose of the curriculum. In the other, the teaching of subjects is the purpose. In the one case, disciplines of knowledge are to be mined to achieve its purpose; in the other, disciplines of knowledge are the purposes” (p.150). One notes here how one educational idea (the Rousseauian project) dominates and is prioritized over another (Platonic knowledge-based project). What offers the advantage though, is that teachers come to be more concerned with pedagogy and the

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83 One could include here U.S. Standards documents like AAAS (1993) and Canadian Common Framework (Council of Ministers, 1997), in so far as both are explicitly lacking an encompassing educational metatheory. The Australian statements on schooling appear similar to typical traditional content-based school curricula (“academic rationalism”), especially IB and AP structured senior science courses. The newer U.S. and Canadian policy documents, it is admitted, do attempt to broaden the understanding of scientific literacy beyond just content knowledge. The Canadian document in fact takes the “knowledge” component as only one of four “foundation” dimensions of literacy, but as mentioned, heavily influenced by the contexts of the STSE paradigm. A recent interpretation of this STSE policy document states that the: “goals of science education have broadened to include personal goals such as lifelong learning ...; social goals like developing informed citizens and a well-educated workforce; and the traditional academic goals ...” (Roscoe and Mrazek, 2005, p.12; original italics). One clearly sees here the three educational goals underlying the document but identified by Egan as being at odds, without any recognition on the part of the authors that fundamental problems lie at hand. It seems that the goals so stated have been extracted as general principles while ignoring (or being unaware of) the theoretical frameworks they are embedded in. As such, these policy documents can be taken as representative of the “second option” for literacy mentioned in Chapter 2 (also Roberts’ “vision II”), being the “inclusivist” option of DeBoer (2000).
learner, and not, as is often the case (at secondary and tertiary levels), see themselves chiefly as subject specialists taking a mere *instrumentalist stance* on curriculum, to expand knowledge in students’ minds. (We will see in chapter 5 this presupposes a rather trouble-free “transmission model” of language and knowledge acquisition). Thereto, Vásquez-Levy emphasizes the importance of *Didaktik* analysis as linked to this project:

*Bildung*-centred *Didaktik* keeps analysis of teaching events/classroom work within the realm of pedagogy and, simultaneously, can engage teachers in deep levels of reflection concerning the what, how, and why of teaching and learning. In this way, *Bildung*-centred *Didaktik* prevents the teacher from being consumed by purely institutional concerns, which may be antagonistic to students’ *Bildung* (2002, 120).

This in fact can help contribute to avoiding the situation where the teacher’s role itself can be reduced to, or predominately taken to be, an *instrumental* one; that is, the teacher as mere “instructor” commanded to implement prescribed curriculum—as is often the case in the *Curriculum view* and school science education generally. The *Didaktik* tradition can suffer this charge, too, if it is reduced to mere instructional methodology. Englund (1998) described such a narrowing to have occurred in Sweden, where later a “broader didactic” based in curriculum theory and philosophical inquiry brought about a renewed sense of didactic analysis. Curriculum theorists widened the view and asked questions about “factors determining *educational* content [of school science content] and ... why certain content was chosen” (p.15). *These kinds of concerns and the type of philosophical inquiry involved are exactly the purview of PoSE.*

I assert that Egan’s metatheory serves the exact same purpose as i) above (but is not subject to the tensions of internal educational inconsistencies inherent to *Bildung*, as previously discussed), and that in addition part of the critical aspect of a *philosophy of science education* for teachers equally serves the purpose of ii) above, acting as a type of *Didaktik analysis*—the involved process by which teachers critically examine how the

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84 “In general, pre-service teachers are taught to begin thinking of instruction by asking how a student learns, how a student can be led toward a body of knowledge, and how to evaluate what students know and are able to do. Such tasks promote a role of the teacher as ‘instructor’, one who is accountable for implementing formalized state-mandated curriculum. This view of curriculum as an organized framework for guiding, directing, or controlling a school’s ... work then determines the range of approaches available to teachers. Thus, this curriculum-as-teaching manual perspective restricts a teacher’s potential ... professional autonomy” (ibid, p. 117).
content can meet the concerns of learners and learning progression when fulfilling the requirements of the educational metatheory (whether Bildung or Egan). Fensham (2004) comments that both traditions (Curriculum and Bildung) have come to understand this procedure of content and curriculum scrutiny as encompassing what Shulman had come to portray as a teacher's pedagogical content knowledge (PCK)\textsuperscript{85}, although it tends to be largely undervalued in the typical science education Curriculum tradition, especially science teacher education programs:

This interaction between content and educational process—a central aspect of PCK—is certainly an issue in Didaktik, but the first stage of the Didaktik analysis, transposing the disciplinary science knowledge itself to the purposes of school science, is often not recognized by those in the Curriculum tradition [p.155]. An alternative meaning for PCK is to regard it as the way a teacher's knowledge of science content is modified by the experience of teaching it (p.156).\textsuperscript{86}

What primarily distinguishes the two traditions then is the way they conceive of, and organize, school science education:

In the Curriculum tradition the teaching/learning stage is most obviously problematic, whereas in the Didaktik tradition, the transposition stage and the teaching and learning stage are both problematic. In the former tradition, the science content itself is essentially given. In the latter tradition the science content is initially the site of the problem, because of the decisions teachers should make about it, and then this content is intimately involved in the problems of its teaching and learning (p.152).

\textsuperscript{85} "It represents the blending of content and knowledge into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction. Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue" (Shulman, 1987, p.8).

\textsuperscript{86} PCK itself has not been an involved area of science education research. Van Driel et al. (1998) closely aligned the idea with a teacher's craft knowledge and stressed its tight link to specific subject-matter topics (they examined chemical equilibrium), and cautioned against inferring to general cases of science learning. They see PCK as a rich area for further study to link research on teaching with research on learning. Abell (2007) has provided the most recent comprehensive review, combing the literature for studies on CK, PK and PCK. She quotes Geddies (1993, p.675) defining PCK as "the transformation of subject-matter knowledge into forms accessible to the students being taught." She admits the category has come under criticism for vagueness and some have questioned Shulman’s model, adding other concepts like "pedagogical context knowledge or concerns" to the lexicon. Some admit to difficulties in providing proper methods for research to collect appropriate empirical data to confirm, disconfirm or expand upon the term. While PCK has been mostly embraced as a useful theoretical construct, research remains "in a formative phase, where researchers continue to define terms and methods to guide their work" (p.1123). She provides valuable sub-topics to better define the CK, PK and PCK classes (Fig. 36-1, p.1107), and suggests five components to PCK: orientations to teaching; knowledge of science learners, curriculum, instructional strategies and assessment. What is missing however, are two important factors: how NoS knowledge influences CK and PCK (deliberately ignored) and the crucial role played by an educational metatheory."
Again, Egan’s metatheory equally problematizes both stages, and he explicitly mentions that the teacher needs to put the subject content for “transposition” in question as well, as a means to satisfy the prior specified metatheoretical educational purposes, including the need to determine the emotional potential of the content for the learner when lesson planning (2005b).

Fensham moreover, goes even further when discussing the nature of science content knowledge (CK; and his insight is noteworthy), when comparing what both traditions have in common as a shared failing: they both still assume that the subject content (as disciplinary knowledge) is itself unproblematic. (The Bildung tradition only problematizes the content form or context for pedagogical transposition and its usefulness as related to the essential aims of the metatheory). Certainly Didaktik does readily acknowledge (in a way that “Curriculum” does not, although Dewey stressed the difference) that the two contexts of knowledge structures is quite different, when organized either in subject specialization (in disciplines like physics, chemistry or biology) or organized for learning for pedagogical and schooling purposes as required by the demands of an educational metatheory: “In other words, the knowledge in these sciences is not automatically in a form that makes it meaningful or worthy of a place in schooling committed to education as Bildung” (p.147). Hence, the crucial role of philosophy of science education, or, on the other hand, Didaktik analysis, as was stated—but most importantly what is still completely missing in both traditions, argues Fensham, is a deeper questioning of the nature of the formal content as structured and offered by the science disciplines themselves. This implies that another vital role of philosophy of science education is to help the teacher scrutinize their own, and indeed their discipline’s content knowledge (CK), and to no longer take these for granted:

Despite recognition in the Didaktik tradition of the need for didactical analysis or transposition, both traditions have, I believe, hitherto, held strongly to the idea that the content for school science subjects should be determined by what is accepted as lying within the content of the corresponding disciplinary science (p.158).

At this juncture I would stress this is exactly where the value and need of history and philosophy of science (HPS) plays a fundamental role to help teachers move beyond
the strict confines of the disciplinary knowledge structures they have been so accustomed to—and been enculturated into—in their academic training, by providing them with a wider perspective on the sciences (informing their image of science and epistemology). Moreover, this offers another criterion to assess the adequacy of their content knowledge (CK) for pedagogical purposes: in other words, in structuring their pedagogical content knowledge (PCK) for better science subject comprehension (see the earlier comment by Matthews, 1994, p.204). This requires science teachers to go especially beyond textbook knowledge and to secure “the ‘deepest objective substance’ of the subject matter and know its educative aspects, and understand students’ internal and external capacities.” Only then is “he or she free to reflect on approaches to teaching” (Vásquez-Levy, 2002, p.124).\(^{87}\) Egan (2005b) expresses a similar expectation for teachers to dig deeper into their subject disciplines (CK) to uncover (or recover) the imaginative potential of the subject for learners (PCK).

One therefore concludes the content must be seen as problematic for two reasons:

1. it needs to be transposed into an appropriate form accessible to the learner
2. it needs to be broadened as a knowledge base, to include NoS studies

With respect to #1, a significant part of the transposition will include shaping the context by using the “narrative approach”, especially as suggested by Egan’s ideas. With respect to #2, the next chapter will address the issue of teacher’s CK and NoS studies.

When one examines Figure 1 which contrasts the two traditions (I have considerably revised Fensham’s original chart; 2004, p.149, Fig. 10.1), the position and purpose of a philosophy of science education for a teacher’s PCK in the schema becomes apparent. Also illustrated is where the nature of science factor (“science studies/HPS”) must be included to allow for a re-evaluation of content knowledge (CK). These aspects are shown in square brackets. Whereas the Didaktik tradition draws upon the disciplinary sciences only as a knowledge source for one component of PCK, the Curriculum tradition in science education is grounded in the disciplines since they normally structure both

\(^{87}\) I understand this to be a proactive stance. Research into science teachers’ PCK also indicates that the relationships are reciprocal in nature, in that CK can be re-evaluated in light of teaching experience and reflection on classroom student learning (van Driel et al., 1998).
school curriculum and teachers’ CK (especially at the upper levels). In addition, metatheory is here markedly absent. Notice how Egan’s metatheory can be situated more easily within the preconceptions of the educational system of the Central-northern European tradition, but posing as a rival to the Bildung paradigm.

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88 At the lower levels at secondary schools in Canada (grades 8 to 10) the science literacy conception according to the STSE paradigm structures the contexts for learning (based on the Common Framework document; Council of Ministers, 1997), as explicitly stated by the BC Ministry of Education Integrated Resource Packages (IRPs) which determine the “Prescribed Learning Outcomes” (PLOs) to be taught.
**FIGURE 1 Two Educational Traditions**  
(Revised from Fensham (2004, p.149, Fig. 10.1), with reference to Shulman, 1987)

<table>
<thead>
<tr>
<th>EDUCATION SYSTEM</th>
<th>EDUCATION SYSTEM</th>
</tr>
</thead>
</table>
| “Curriculum” Tradition (Anglo-American)  
(Conventional) | “Didaktik” Tradition (German/Norse) |
| CURRICULUM BOARD | CURRICULUM BOARD |
| Science content to be taught [CK]  
(knowledge-based core curriculum) | Education Metatheory  
(eg. Bildung)  
• Disciplinary sciences  
[Science Studies; HPS]  
(knowledge sources CK) |
| [Science Studies?, HPS?] | [Egan’s Theory] |
| TEACHER | TEACHER |
| “Didaktik analysis”  
[“Philosophy of Science Education”] | |
| Knowledge for school science [PCK]  
[eg. “HPS Narrative approach”]  
[eg. “hermeneutics of knowledge and of understanding when learning”] | |
| Appropriate pedagogy [PK] | Appropriate pedagogy [PK] |
| LEARNER | LEARNER |
3.2. Kieran Egan’s Educational Metatheory

Egan’s ideas on imagination, learning, development and curriculum which underpin his metatheory have been developing for several decades and been described in previous books. The most complete articulation of the metatheory—occasionally referred to as “imaginative education”—is found in his (1997) *The Educated Mind: How Cognitive Tools Shape Our Understanding*. Polito (2005) has recently (and correctly) discussed how his metatheory is linked with the cultural-linguistic development of humanity, especially by portraying its features in sharp contrast to Dewey’s ideas, and Hadzigeorgiou (2006) has emphasized its value for humanizing physics education. Thus, while Polito helps paint the broad picture, Hadzigeorgiou exemplifies with the concrete, and I have chosen along with the former to contribute with a further sketch of the wider canvass. Many researchers in and outside of the HPS movement are already familiar with his earlier ideas stressing story-telling and narrative as a vehicle for providing curricular context to enhance instruction and learning (Egan, 1986/89; Stinner, 1995; Matthews, 1994).

His construction of the metatheory has grown from an awareness of the perceived carnage brought about by the misapplication of psychological theories in education (2005a; 2002; 1983)—including a large measure of skepticism towards the ability of research findings to inform educational theorizing—bringing forth various (aforementioned) separation arguments. Since these arguments equally serve to underpin and shape his alternative metatheory, let me therefore first focus on these before examining Egan directly. The serious charge he has leveled against uses of such theories in education (with the view that psychological and educational metatheories must pass one another by because of the inherent differences with respect to what each seeks to describe, explain and apply) is grounded on two big arguments.

---

89 His (2005) *An Imaginative Approach to Teaching*, presents several useful frameworks which illustrate how this metatheory can be applied to curriculum and practice for different subject topics and themes. This book, along with the continuing research of the Centre for Imaginative Education (IERG), has brought his ideas to bear in fruitful ways in a number of diverse cultural classrooms around the globe, being applied from primary to tertiary education. My discussion will focus solely on his high-level theory in *The Educated Mind*, and the reader is referred to his (2005) and encouraged to visit the ierg-website (www.ierg.net) for related information about theoretical applications for teacher classroom use.

90 He writes that an educational metatheory “shows how to realize in individuals a certain conception of education. Without some such conception, all the research findings in the world are educationally blind, and with such a conception, it is unclear what research findings have to offer” (2002, p.181).
The first big argument (also cited by Aldridge et al., 1992) insists that for education and unlike for psychology, there exists no natural educational process to describe or explain, rather “an educational process exists only as we bring it into existence” (Egan, 1983, p.3). It is the business of educational theories to be prescriptive while for psychological theories it is to be descriptive of an assumed “natural development” of human beings at various stages, with the aspiration of becoming explanatory and normative. At most then, psychology’s descriptions of cognitive development, say, can serve as constraints to the educational project of what is deemed of value for developmental stages and goals. While this may seem sensible, and while this assumption is indeed taken for granted in most educational practice (see Gredler, 1992, as typical), Egan himself is skeptical and cautions against “psychological description constraining educational prescription”.

He gives examples from Piagetian influenced researchers who have shown that young children lack those concepts necessary to make meaningful sense of abstract ideas like “religion” or “history” (and I would add “science”). While valuable information it unfortunately provides the educator with no basis to decide “what”, “when” or “how” to teach ideas which will eventually contribute to the development of such important concepts. How such knowledge is to be evaluated and used is precisely the task of an educational theory. Sadly, too often the deduction has been made that such subjects are themselves irrelevant until the appropriate “stage” has been arrived at by the learner and hence should not be taught—a conclusion Egan refers to as the “psychological fallacy”. Its pervasive influence “is a tribute to the power of psychology over education, and the theoretical poverty of education” (p.12). It follows that common terms of use such as “learning”, “motivation” and “development” could very well have different connotations in the two disciplines.\footnote{This does not necessarily force a complete separation between the two disciplines but it certainly appears to further widen the gap between psychological theories and educational practice.} Furthermore, not only are psychological theories contested—including the isolated, artificial and controlled conditions in which many empirical results have been undertaken—one cannot even be sure what exact constraints of our nature are supposed to be described by them, given that when considering human behaviour it is difficult if not impossible to separate nature from culture (Cole, 1996).
This brings us to his second big argument. There need be no reason why cognitive "development" as elaborated by cognitive psychology should resemble cognitive development as described and prescribed by an educational high-level theory. It belongs to the aspiration of a scientific-oriented psychology modeling itself on the natural sciences that among the criteria for its scientific credentials belongs the assumption of an underlying "nature" common to all human beings that can be unearthed and abstracted beneath the domineering layers of a socializing culture. Indeed, Piaget's stage theory of cognitive development is premised upon exactly such a postulate, and "is derived from his analysis of the biological development of certain organisms" (Gredler, 1992, p.222), what I had previously referred to as the organismic metatheory in psychology (Kitchener, 1992). This viewpoint is actually an old one and goes back to Aristotle, and it runs through progressivism (Egan, 2002). One could call it the age-old quest for the "biologized mind". Egan, following Vygotsky's socio-cultural outlook, is diametrically opposed to such a conception of mind—which he considers a fiction—and rejects as a false belief the corollary that children's minds have a preferred natural kind of learning which can be isolated and explained by psychological research. Rather, it may be precisely the culture forming conditions of mind that an educational theory may wish to foreground and as such may prove invaluable for the educative process, the very thing a scientific-oriented psychology hopes to minimize if not in fact to eradicate from its research programme.

Much of what is most distinctly human in learning and development has been suppressed by the search for the biologized nature of the mind. That search has avoided the cultural stuff that seems to constitute mind and is not particularly amenable to study by research methods devised to deal with the natural world ... there is no naturally preferred form of human intellectual maturity. We are not designed, for example, to move in the direction of "formal operations" or abstract thinking or whatever. These forms of intellectual life are products of our learning, "inmindating", particular cultural tools invented in our cultural history" (Egan, 2002, pp. 113; 114).

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92 "Piaget ... is not interested in those concepts which occur "artificially" as a result of instruction, but rather in those concepts which develop spontaneously or naturally as a result of normal interactions with the environment. He is interested in what happens of necessity in the development of cognition. An educational theory is concerned with making value choices among a variety of possibilities. One does not choose to do what is necessary. ... it makes no sense to try to teach concepts which develop naturally" (Egan, 1983, p.16; original italics).
93 "We have suffered from tenuous inferences drawn from insecure psychological theories for generations now, without obvious benefit" (Egan, 2002, pp.100-101).
It goes without saying that should the central assumption of the existence of an underlying nature common to human cognitive development turn out to be false, it would have serious ramifications for the self-conception of a scientific psychology. This is not our concern here, though, nor does the merit of Egan’s argument require its overthrow. It just requires that such a nature remain if not irretrievably buried beneath, then at least irrevocably shaped by, human cultural history (as Bruner, Cole and others working within the socio-cultural school of psychology now argue is indeed the case; Kozulin, 1998; Cole, 1996).\textsuperscript{94} This brings up the significant question to what extent mind can be considered a legitimate scientific object of study. There is currently much debate on this subject, with “mind” being located somewhere between the cerebral cortex and culture (Leahy, 2005). Egan’s sympathies clearly lie more with those who hold what has been described as the “strong culturalism” view (Bakhurst, 2005).\textsuperscript{95}

With these arguments in view, and supposing such a take on “mind”, Egan has constructed his metatheory using insights gained from many diverse fields, drawing upon anthropology, cognitive science, philosophy, history, linguistics and classical studies, and following in the tradition of the Russian socio-historical approach to psychology and education (Kozulin, 1998; Cole, 1998; Moll, 1990; Wertsch; 1985; Vygotsky, 1978). In sum, its hallmark features the significance of the three central ideas of imagination, the mediation of socio-cultural cognitive tools and recapitulation. Each one of these three complex and historically-loaded ideas is carefully explicated in his works, and because of brevity I can only sketch them here. Yet for many educators, and especially for science

\textsuperscript{94} Howard Gardner has also come to this realization: “The category of “natural development” is a fiction; social and cultural factors intervene from the first and become increasingly powerful well before any formal matriculation at school . . . Once the child reaches the age of six or seven, however, the influence of the culture—whether or not it is manifested in a school setting—has become so pervasive that one has difficulty envisioning what development could be like in the absence of cultural supports and constraints” (1991, p.105).

\textsuperscript{95} See his 1997, p.30. Bakhurst (pp. 413-4) writes: “Those that invoke the slogans that the mind is “constructed,” “distributed,” “relational,” “situated,” or “socially constituted” to maintain that culture is in some sense constitutive of mind, and that therefore the nature and content of an individual’s mental life cannot be understood independently of the culture of which that individual is apart. Strong culturalism can take various, more or less radical forms . . . [it] starts from the old intuition that reductionism (or eliminativism) about the mental leaves out something crucial . . . the missing ingredient is not primarily consciousness or phenomenology, but the sociocultural context of mind. Two intuitions lie behind this claim. [Firstly] that meaning is the medium of the mental, and meaning is . . . a social phenomenon. [Secondly] . . . the human mind, and the forms of talk . . . should be understood on the model of tools; and like all artifacts, we cannot make sense of them independently of the social processes that make them what they are.”
educators, such ideas may sound strange and radically new, accustomed as they are to the
more conventional discourse, one dominated by language fashioned by knowledge
structures ("subject disciplines"); "curriculum content") and psychology ("cognition",
"learning as information processing"; "stages of development"; etc.). And yet his three
main ideas are themselves part of a rich historical and educational background, which for
the case of imagination alone is considerable, running through Western thought as it has
and stretching back to its early differing appraisals both in Ancient Greece and the Judeo-
Christian religious heritage.

Egan’s metatheory is grounded on the fact of the historicity of language in human
anthropology and cultural development and how this has managed to shape—albeit in
ways not yet entirely understood—both the brain and the mind. "Without the historicity
of language, human nature and the human mind remain essentially unchanged in history"
(Polito, 2005, p.486). This position stands in sharp contrast to Dewey and his
philosophical anthropology, which undergird his philosophy of education:

There is no historicity of language in Dewey; therefore there is no historicity of
consciousness. For Dewey, man’s consciousness has remained fundamentally the
same since the birth of its existence to the present. The form that consciousness
takes is to inquire about the outer world in relation to the needs of self-
preservation ... it is this technological advance which drives language
development. ... Like Vico, Egan believes that we could not have acquired the
capacity to think in consistent and controlled manners proper to rational adults
except by first being able to think imaginatively and associatively. ... For Egan,
language and reality develop in constant interaction with each other. Language
responds to the world’s changes and, in turn, changes the world (Polito, 2005, pp.
485-6).

One can assert without much controversy that there has been a general cultural
progression of the human race from plain mimicry and artifact construction (common to
our primal homo sapiens ancestors), to oral language use, literacy and finally to more
complex forms of language symbolism and use, including theoretical thinking, as noted
by many—though, granted, such a development has been largely uneven and not
universally realized by all cultures. Even today, although a few remaining aboriginal oral
cultures have managed to withstand the test of time, they too, will inevitably enter the
cognitive and physical space of literacy, which will, in turn, significantly shape their
culture and mind for good or ill, as it has for all other human societies—including as examples, the early Maya, the Arabian tribes (which gave rise to Islamic civilization in the 7th century), and Germanic and Slavic oral cultures which, when schooled in literacy by the Greeks, Romans and Judeo-Christians, would transform (and themselves be transformed by) the Ancient world and create early medieval Europe. The exceedingly long historico-cultural development since our early hominid prehistory, which appears to be neither inevitable nor ‘progressive’ (in the older 19th century evolutionary sense), has nonetheless brought with it the discovery and invention of both physical and especially cognitive tools, which according to their own sequence and time have wrought technological advance as well as expanded the human capacity to reason.

What is of importance here is that with each major cognitive transition (body-centered mimetic to oral language to literacy and numeracy) have come an array of other specific cognitive “languaged” tools which have correspondingly formed the mind and broadened human understanding to grasp and make sense of the world, and which Egan further claims to have identified and catalogued. Where the knowledge of this cultural-linguistic developmental framework becomes useful for education is as a recapitulation premise: that children while growing up are themselves remarkably going through a similar bodily and linguistically-based cognitive development in their personal growth, and Egan argues it is the task of an educational theory to help learners recapitulate—that is, become aware of and maximize—the use of the mental tools at the appropriate stage that comes along with such a development. And as with human cultural history, so with students, the use of the imagination is crucial in bringing about the success of such a cognitive recapitulation; in effect it drives the process. Egan’s metatheory in short is an extended argument for making possible the recapitulation of the co-evolution of human cognition and culture as an educational undertaking. This has never been articulated as an educational project before, certainly not in any philosophy of education I am aware of.

Egan has proposed a detailed five-stage progression that represents five different kinds of human “understanding”: somatic (or body-mimetic); mythic; romantic,

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96 “What the imagination can grasp is enabled and constrained by the logic inherent in the various forms of knowledge and by the psychologic inherent in the process of human development. So the dynamic of this scheme is a troika of generative imagination guided and constrained by epistemological and psychological forces” (1997, p.189).
philosophic (or theoretic) and ironic. (These bear resemblance to Merlin Donald’s study of human cultural history in his *Origins of the Modern Mind* (1991), who suggests a three-stage cultural succession of mimetic, mythic and theoretic—brought about by the tools of the body’s mimetic skills, oral language and external symbols, respectively). Notice the emphasis here, in contrast to traditionalism, is not focused on knowledge structures *per se* (although these are of value) as an enabling of a fuller comprehension of subject matter due to the mental make-up or *assembly of mind* already at hand (and in process of moving on to the next assembly). He has further distinguished the five by presenting and analyzing an inventory of “sub-tools” characteristic of each (I list a few below). In addition he has suggested *approximate* ages for when the learner can be expected to enter the particular stage, when the cognitive tools are first stimulated:

- *somatic* (sub-tools: bodily senses; rhythm and musicality; gesture; reference); pre-linguistic and extra-linguistic thinking; body use to represent thought, action and communication; appears before humans invent oral language; (children ages 0 to 2).
- *mythic* (story; metaphor; binary opposites; humor; images; sense of mystery); oral language stage; associated with oral societies; (children from 2 to 7 years).
- *romantic* (extremes of reality; heroes; wonder; revolt and idealism; hobbies); literacy stage generates a “new consciousness”; (children from 7 to 14/15 years).
- *philosophic* (drive for generality; general schemes and anomalies; search for authority and truth); “theoretic thinking”; associated with academies (adolescence).
- *ironic* (limits of theory; reflexivity and identity; radical epistemic doubt); reflexive use of language; poetic and meta-cognitive thinking; (early adulthood).

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97 Egan has focused to a greater extent on the mental effects due to the advanced stages of literacy, especially as displayed by human culture in the relatively recent past, the last 5000 years or so, above all regarding changes to Greek society and thought. The “romantic” stage can also be seen as forming a *transition* between mythic and theoretic, while “ironic” is that end stage where “language becomes aware of itself” and its own limitations. For the latter, Egan’s archetypes are, in ancient times Socrates, and in modern times Kierkegaard and Nietzsche. He distinguishes a positive “sophisticated irony” which can manage doubt while preserving aspects of mythic, romantic and philosophic stages, from an “alienating irony” of the typical postmodernist sort—it yields instead to radical epistemic doubt, to rejection and dismissal of the other understandings. “The product of alienating irony is impotence; sophisticated irony is liberating and empowering. The aim of educational theory is to keep alive as much as possible of the earlier kinds of understanding in the development of irony” (1997, p. 162).
These five kinds of Understanding (or “super tools”) to all intents and purposes need to be recapitulated in the classroom, according to Egan, in order for education to work best. The Understandings are not to be viewed as hierarchical, rather as intellectual-concentric, with one coalescing into the other over time—though there are some losses along with the accumulated gains (memory, for example, is much more powerful in oral language cultures). The last four above all can be taken as our “languaged engagements” with the world and represent increasing “degrees of culturally accumulated complexity in language” (1997, p.30). The connection between “cultural development in the past and educational development in the present” (p.27) are the elements and stages of the culturally mediated cognitive tools common to both. What had begun long ago but now surrounds the growing child, the socio-cultural entrenched cognitive tools become gradually internalized in successive stages. So Egan makes broad use of Vygotsky’s original notion of cognitive tools but exploits and extends them in novel ways unique to the educational context.

To a large extent, Egan admits, the degree to which the “understandings” are maximized and which sub-tools are stressed over others is itself culture dependent. Moreover, they are only imperfectly developed in the normal course of human maturity, partly because the “understandings” and their sub-tools have not been made explicit and largely because educational systems have either undervalued or ignored them. Some come more easily with maturity and socio-cultural embeddedness than others, although they are poorly harnessed for effective instruction and learning in typical school settings. Because “mythic” and “romantic” thinking are intimately linked to our emotional selves, they are ubiquitous in the everyday world: in the media, the entertainment industry, pop culture and political rhetoric. “Philosophic” understanding (or perhaps better put as “theoretic thinking”), on the other hand, is acutely fragile; it

98 Egan is careful to distance himself from the two earlier and unsuccessful versions of recapitulation: the logical one which insisted a particular cultural (knowledge) content must be followed (Herbert Spencer), or the notorious psychological development version with its biological basis, and now discredited (once supported but later repudiated by Dewey and Piaget). See Langer (1988). Egan’s reference is strictly to socio-cognitive tools as invented in human cultural history.

99 “Intellectual tools, or sign systems, begin, to use Vygotsky’s terms, as interpsychic processes and become intrapsychic within the child” (Ibid., p.29).

100 This is exactly what Egan laments about contemporary education, along with the well-intentioned but misguided practice of using unsuitable psychological theories when transmitting ‘inert’ knowledge, and all the while hoping to juggle three conflicting goals.
represents a fairly late flowering of human history and civilization and requires institutions (schools, universities, research bodies, art and music colleges) for its achievement and advancement.

The *aim of education* is thus redefined in this conceptual framework to produce a kind of “five-fold mind” (although this label can be misleading), one that is conscious about and can make *use* of the five cognitive-cultural “toolkits” (along with their various listed sub-tools) when exploring and thinking about the world, be it created by nature or constructed by man. The ‘how’ and ‘when’ of teaching any curriculum is answered by *organizing* subject topics around the cognitive tools and sub-tools available at the corresponding stage of development of the learner—which would engage their imagination, emotions and interests in a natural way, because these are the dominating ‘thinking’ tools available to them at that stage. Another way to phrase it, the student’s “mind” is to become ever more sophisticated by developing five cognitive “layers of understanding” when dealing with the world—this goes greatly beyond the perennial concern in science education to develop better problem-solving or “critical thinking” skills of mind (Bailin, 2002; DeBoer, 1991), although such skills or habits are undoubtedly involved.

### 3.3. Egan’s Metatheory and HPS Science Education

The relevance of his metatheory to science education can now be answered and sketched, pertinent to *two levels*, the general and the more specific curricular level.

Let us focus on the *specific* or curricular classroom level first. Because it serves primarily as a theory of (educational) *development* it bears directly upon how learners can be expected to come to *understand* at appropriate age-grade levels, and liberates science education from the domination of ideas in developmental psychology (Egan, 2005a; Duit and Treagust, 1998). For example, all in the community are agreed (regardless of paradigmatic commitment) that it makes no sense to present science to learners in primary school from the “logic of the discipline” perspective as is done in senior secondary. Along with other developmental theorists, Egan also seeks to explain *why* this is the case. In marked contrast to how some developmental theories in psychology *attempt to explain* the quality of children’s reasoning ability (with their narrower focus on
personal cognition and the logical-mathematical category), the explanatory power of his metatheory arises from the changed nature of the discourse, with the shift of focus towards social constructivism and children's cultural-linguistic mental assembly—it is because their developing minds are inherently shaped at this younger stage by 'mythic' cognitive tools, and not because they are "pre-operational" (or whatever). And at middle school, where the "logic" approach begins to encroach increasingly, Egan explains why this approach must also miss the mark in capturing students' interest and study since their 'romantic' make-up of mind inherently searches for meaning and knowledge within that frame. Any amount of motivational coaxing or suggestions from psychological learning theories can have but little effect. Even at the upper levels Egan suggests that the logic of the subject matter could be better understood and appreciated if molded according to their developing 'philosophic' frame of mind and its sub-tools. That the logic of subject-discipline organization is a very poor place to begin to learn a science subject (as so much PER and CER work continuously confirms), because it represents the end-stage of knowledge generation and storage, had already been cited by Dewey (1916) almost a century ago—yet, sadly, such an approach remains ubiquitous. Why not work with what cognitive-emotive tools the learner already has, though in latent form?

Now I would like to list a few brief examples of how Egan's metatheory could impact the science classroom. His (2005) has illustrated how the life-cycle of the butterfly could be taught in an imaginative way within the mythic framework to foster and develop those tools for making this topic better understood and more engaging for learners in primary classrooms. He has also provided instructional frameworks to develop 'philosophic' understanding at the upper levels for learning calculus, Newton's laws and simple harmonic motion, so there is no need to repeat these here. What I would like to underscore is how he has interwoven an emphasis of narrative as a thread throughout the tool-using and learning stages. At the 'mythic' stage learners are engaged emotionally with story-telling, as is well-known, but he goes on to show how this becomes shifted to a

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101 And the newer explanatory cues offered by studies in neuroscience on the so-called "adolescent brain" while suggesting some physiological constraints hardly addresses the issue of their development of mind. (Kwan and Lawson, 2000). This is once again to defer to a reductive empiricist notion of mind, possibly organismic.

102 It also formed part of the later critiques by Lawrence Cremin and Paul Hurd at the time of the 1960s scientist-based curricular reforms (Bybee and DeBoer, 1994), but to no avail.
narrative format in ‘romantic’ understanding and on to metanarrative at the ‘philosophic’ stage. One can, of course, still tell engaging stories at subsequent stages and grades, but Egan shows how to structure the subject topics around these important tools in effective ways for instruction. What he is doing is drawing out the richness and meaning-making capacities of story as the mind develops and begins to seek out more complex and varied forms of understanding through narrative (Lyle, 2000). This is precisely where the proper use of the history of science can enter, enrich the narrative format and deepen comprehension of the curricular subjects. Egan can in fact provide a practical and pertinent metatheoretical justification for the contextual-historical case study approach as presented by the Stinner research group (2003) and as applied by them to age-developmental curricular topics for the early, middle, senior and college years.

As Klassen (2002) has clarified, the rationalization for the use of the history of science in the curriculum has been most commonly for the dual purpose as providing context and for enhancing cultural literacy. Especially at the upper levels, students usually do not come to “feel the excitement” of original scientific discovery (e.g. of the electron, DNA or the Copernican revolution). Rarely are they presented with the “big picture” of the theory which commands a discipline in terms of how it came to be originally formulated (what problems or other theory it confronted), was debated, perhaps was suppressed, even challenged and occasionally overturned because of recalcitrant anomalies and argumentative discourse. Instead, students in senior and college courses are drowning in specialized content—in a sea of facts, descriptions, laws and equations. Egan insists that some sort of metanarrative that provides an overall explanatory frame of scientific knowledge, change and advance should be presented to students at some point in their science education at the upper level. Although he suggests Thomas Kuhn as a possibility, and one may quibble with that choice, I think his premise has considerable

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103 “A narrative is a continuous account of a series of events or facts that shapes them into an emotionally satisfactory whole. It has in common with a story that shaping of emotion, and so words are often used synonymously, but it is different in that narratives can be less precisely tied into a tight story, less concerned with emotion, more varied, more open, more complex” (2005, p. 99).
merit. Should there not be any time allotted in the curriculum for those cases where rival high-level theories have clashed in respective sciences (see here Duschl, 1990)?

Egan argues that due to the learners’ sub-tools (listed earlier) and their emotive link, the “general schemes” should be up front at the start. The power of theories for explaining and generalizing over many phenomena for instance, coincides with the cognitive sub-tool of the “drive for generality”; this feeds into their sense of meaning connected to the “search for truth” and the “lure of certainty”. And the histories of physics, chemistry, biology and geology are all well positioned to present to them how “general schemes” (theories) remain incomplete and the important role of debate and anomalies in the scientific community in any revolutionary overthrow. This hooks’ directly to student fascination with the discipline and its evolution, it humanizes the content and opens up questions about the nature of science (including the epistemic status and role of models)—all of which allow for better content acquisition. It would certainly help get behind the dry, dogmatic and static “textbook science” and begin to expose the wonder and dynamism of the historical and cultural development of the scientific enterprise—all components HPS reformers have argued for decades. Certainly some socio-scientific issues (SSI) that are consequent of “frontier science” could also be of relevance here for enhancing the “tool-kit” for philosophic (theoretic) understanding.

Finally, at the general level, the impasse in the three major goals of science education (as argued in chapter 2)—and which lies beneath the contested science literacy conceptions (as stated at the start of this paper)—is mostly resolved, or so is claimed: in so far as the discipline would no longer be preoccupied with debating whether and how specialized content knowledge should be stressed at the cost of teaching and learning

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104 As examples, Ptolemaic or Keplerian astronomy; Newtonian or Einsteinian physics; phlogiston or Lavoisier’s chemistry; young-earth theories or evolutionary geology, etc.; For those researchers who now argue for the value of stressing model-based reasoning, the particular limits and defects of the respective models of such theories become sharp. Such instances can serve as an effective teaching strategy to help students discover how knowledge can progress, and thus illuminate for them the precarious nature of how science actually advances—along a “paradigm shift” (Kuhn) or along the lines of progressing or degenerating “research programmes” (Lakatos). Duschl (1990) on the other hand, has presented an intriguing alternative view, using Laudan’s philosophy of science, as better suited for science educational purposes, making good epistemological use of several key historical case studies. Alas, conventional instruction rarely elucidates the conceptual structure of even the successful, dominating theory/paradigm (e.g. Newton; Darwin; plate tectonics; early quantum theory), and even less so does it take sufficient time, if at all, to study the fascinating historical examples of how science deals with cases of competing theories. Where historical development is mentioned, that only too often borders on myth, as many HPS researchers have long complained (see Allchin, 2003).
about wider socio-technological issues as preparation for active "critical citizenship", or how both these aims should accommodate (in some way) individual learners, to develop their autonomy and creativity, free from societal constraints, values and demands.

Instead, the overarching aim of science education would be (as simple as it sounds but as difficult as it may be to implement), to assist the learner to master the socio-culturally determined "thinking and emotive tools" available at the appropriate stage of development\textsuperscript{105} for the curricular topics at hand. This offers a fourth, and completely different alternative as to "why, what, and when" one should educate. This does not so much unravel the long-standing deadlock between the socialization or knowledge-based aims, as removes them both from the direct task of educating, on the one hand, and shifts the perennial "social relevancy" requirement (DeBoer, 1991) to a different plane, on the other. The claim is made that when teaching the science content with the tools included at the start in the curricular and instructional planning, students’ imagination will become engaged and connect immediately and more intimately with the knowledge and themes presented to them. Knowledge is still very important in this metatheory, but imaginative education helps unlock the long discovered and encoded forms and fills them with new meaning. Imagination is not to be taken as the enemy of reason, as the older romantic school and popular opinion would have it, but preferably "Imagination is Reason in her most exalted mood", as Wordsworth (The Prelude, XIV, line 192) so sublimely put it, some time ago.

We can easily forget that learning symbols in which knowledge is encoded is no guarantee at all of knowing. All knowledge is human knowledge; it is a product of human hopes and fears and passions. The primary trick in bringing knowledge to life from the codes in which we store it is through the emotions that gave it life in the first place in some other mind. Knowledge, again, is part of living human tissue; books and libraries contain only desiccated codes. The business of education is enabling new minds to bring old knowledge to new life and meaning (Egan, 2005b, pp. 96-7; my italics).

This knowledge, now filled with fresh significance because it is placed within a narrative context will be better remembered and truly understood, and, so goes the

\textsuperscript{105} One avoids the term ‘growth’ here because it is tainted with Dewey’s preconceptions and tied to a biologized view of mind.
argument, can be better assessed and used as the individual finds necessary—whether for personal-aesthetic intrinsic aims or social-oriented utilitarian ends. In particular, and to the point of socialization, a true five-mindedness which has mastered the cognitive-emotive tools by the end of schooling should be able to accomplish what the external social forces so often demand of science education with their vocational push for “productive citizenship” and the many internal (science education) reformers demand for “critical citizenship”—when “socio-scientific issues” are raised, whether at points linked to science curricular themes, or after school and later in life (and as is widely accepted the traditional academic-oriented curriculum with its “vision I” literacy view constantly fails to accomplish). And the demand to allow for personal “growth” and individual creativity would also be met by this metatheory, precisely because it foregrounds student creativity and imagination in learning in various ways, at different age levels. By having the school educational enterprise now focus on developing these “mind-frame” tools of understanding, a cognitive and affective dynamic is established which, in principle, would allow these other decidedly important aims to effectively “get off the ground” and be met, since they would come along as by-products during the fulfillment of the educational project. Tools are tools for a reason; they can be put to work in various ways and for different ends.

In short, science education would now no longer be solely preoccupied with formal knowledge mastery or socialization or growth per se (as ultimate aims), as it would be on tool development and mastery by which these others could then be more effectively and eventually accomplished. And science education could not hope do all this on its own; that would be expecting too much of it, but only within the larger scope of the educational endeavor of the school and college curriculum—one that itself is hopefully immersed in imaginative education to some degree. In any event, such a metatheory directly ties educational means to educational ends rather than, as is usually done, educational means to socialized or psychological or some other ends.
3.4. Summary

Those who wish to structure science education to aim for the exclusive development of a kind of person I argue must overshoot the boundaries of what it is feasible to do and aim for in the discipline. And it is to forget that we do not labour alone, as if isolated within educational institutions, in our disciplines in schools and colleges (although many of us operate as if we do, and when scanning the science education literature one easily receives this impression). It is in the purview and value of an educational metatheory to mark out the ideal, the kind of person, it is true, and I believe we will be more successful at developing and marking out a kind of “scientific” mind-set in cooperation with others when working towards that wider humanistic and global goal within the defined educational frameworks of a metatheory, when at last such an all-embracing framework is drawn up and eventually accepted by the community. (Or possibly one or two defining metatheories). I have suggested Egan’s metatheory, developed exclusively by and for educators (as Piaget himself had suggested some time ago), as one possible and substantial contribution in that direction. This assumes that such a high-level theory is not only essential and beneficial, but equally a prerequisite to establish science education upon a more firmer foundation as an independent academic discipline (but within educational studies)—notwithstanding critical voices who disagree with that position and reject its very premise.

In the interest of avoiding misunderstanding, the argument that science education requires a metatheory is not made on the grounds that simply because education—in the Anglo-American “Curriculum” tradition—does not have one therefore Egan can be suggested as a theorist to help fill the gap; rather on the grounds that because of some serious problems with science education, I noticed a gap, and one I thought could (in fact should) be filled for educative reasons that can address these problems and better serve science education—and that that is something worthwhile pursuing. It is not about filling gaps for gaps sake. Nor am I saying that any metatheory will do, so long as the gap is filled; in point of fact, when comparing the German-Norse Didaktik tradition and educational system—one which actually does employ a metatheory—it was argued that Bildung as a viable alternative is insufficient for several reasons. In short, I am saying:
“this particular metatheory will help (ie. Egan’s) and it can stand on it own merits”
(whether or not it happens to cohere in the mind of the critic).

The problem regarding the deadlock of the three venerable older educational projects with their three key goals time and again vying for priority is not so much “solved” (one cannot “square the circle”) but instead put aside for a fresh alternative which conceives of education in completely new terms of developing the language-based age-appropriate cognitive-emotive tools. We can contribute significantly to helping students at various stages of their development in learning about and using, to their best abilities, the socio-cultural tools through the medium of science, its history, epistemology and socio-technological impact. Science, in turn, will be better understood and appreciated when approached through the socio-cognitive tools, imagination and narrative framework, or so it is argued. (The validity and viability of the metatheory, it is agreed, must be appropriately substantiated in classrooms.) Indeed, that is in the purview of our knowledge and training, and fully within our area of expertise, and would distinguish our unique contribution. Such a restricted aim for our discipline is quite achievable and we would not be saddled with unreasonable expectations and burdens we could not hope to meet, especially with regards to socialization. Surely, it is the business of society to socialize, but the proper job of education is to educate. Regrettably, these two are too often conflated (Nyberg and Egan, 1981).

Science education (and its newer reform approaches) has been largely (but thankfully not completely) remiss on this issue and has for too often and for too long failed to adequately consider this distinction and flesh out its relevance for the discipline. Instead it has become bogged down in focused disputes concerning constructivism and epistemology or endless debates regarding goals and defining science literacy, especially with the well-meaning but flawed primary aspiration to make science students better citizens. It is, further, precisely on this point that the hoped for ambition of achieving widespread public literacy of science (above 20% say)—and hence the wider and by now conventional meaning of “science literacy” with regards to socialization (along STS lines or primarily “socio-active citizenship”, as versions of “vision II”)—is unachievable and unnecessary, as Shamos has forcefully argued. This is chiefly, but not solely, because such a goal is inexorably meshed with other socio-cultural forces, interests and values.
(themselves time and culturally constrained) *external* to school science and the research community which they have but little influence and even less control. What is more, this goal is intimately tied to aspects of an implicit philosophy of education (based on Deweyan and by now suspect progressivist principles) that continues to mark out the principal role of schools and the nature of the science curriculum mainly on socio-utilitarian grounds. The hazards are well-known but easily overlooked. These grounds, at best tend to downplay the personal development of the individual (*Bildung* tradition) as they strain the social allegiance of science teachers to academic science, and at worst, tend to diminish the value of knowledge and the aesthetic, creative side of science. They can just as easily fall victim to economic utility rationales in the face of powerful political forces which too often seek to bend policy in their own interests.\(^{106}\)

With regard to Egan’s metatheory, on the other hand, an opportunity is at hand to have school science education stand its own ground and, first of all and finally, argue the validity and purpose of the discipline on merits derived solely from an “inside” educationalist perspective. With this metatheory taken as an *over-arching aim* of science education, a kind of “five-fold tool-equipped scientific mind” (for want of a better description) could equally serve as an *intermediate aim* in the wider educational project suggested. *Scientific literacy* could then be, I suggest, plausibly and practically reinterpreted to mean the creation of a dynamic science mind-set imbued with its five kinds of *understanding*, all developed sequentially. This is to choose neither of the three earlier mentioned options which currently confront and confound the community, but rather to put the stalemate and the entire discourse aside for a new interpretation and a substitute philosophical educational discourse—conceivably a “vision III”, appropriating Roberts’ (2007) terminology. Science education would then be (in part) reoriented to an internal discussion of what should constitute a proper “scientific mind” along these lines—among those of us concerned for developing a *philosophy of science education* (including debating the very conception)—no doubt a cross-cultural and critical one. (It would certainly be fair to consider my proposal to be linked to the traditional, extended

\(^{106}\) But granted, this failing could also be leveled at conventional science education (at upper levels) taken as the “academic rationalism” (Eisner, 1985) program of the status quo (Hirst/Platonic knowledge-based tradition). This is evidenced not only today (Pedretti *et al*., 2006; Fenham, 2002), but by its very inception during the 1950s/60s major curricular reform wave (Oestman and Roberts, 1998; Klopfer and Champagne, 1990; Duschl, 1990).
conversation on “mind” within the discipline as uncovered by DeBoer (1991), but with a
different accent and orientation, and a greatly expanded conception based in part on
Vygotskian socio-cultural ideas). It would, at least as I construe it, involve significant
study into the epistemology, social practices and history of science (intellectual and
social), along with socio-technological and environmental issues related to scientific
discovery, advances and applications. Here is exactly where HPS reformers can
contribute vital and exceptional insights, and where hopefully a new research direction
can be undertaken with the vision of establishing “philosophy of science education” as a
specialized sub-field of inquiry. It is to boldly state that the field of science education
research should be significantly broadened, as Jenkins (2001) has suggested, and become
more philosophically attuned, as Roberts and Russell (1975) and more recently Anderson
(1992) and Matthews (1994) have argued, and be partially charted—with critical
qualifications—along lines Ernest (1991) has outlined for his “philosophy of mathematics
education.”
CHAPTER FOUR: Philosophy of Science Education, Epistemology and Nature of Science (NoS)

"Every science curriculum, regardless of its professed goals, should at least make clear to students what science is and how it is practiced. Dispelling misconceptions of the nature of science is the first step toward true science awareness. Then follows an understanding of the nature of the enterprise."
—Morris Shamos (1995, p. 224)

"The reciprocal relationship of epistemology and science is of a noteworthy kind. They are dependent on each other. Epistemology without contact with science becomes an empty scheme. Science without epistemology is—insofar as it is thinkable at all—primitive and muddled."
—Albert Einstein

4.1. Philosophy of Science Education, PCK and Content Knowledge

This chapter is about putting into question the nature of curriculum substance, thereto, asking questions pertaining not just to the nature of scientific knowledge, but how this knowledge is represented as subject content knowledge in science education which then informs both students’ and teachers’ views of their image of science (Matthews, 1994). Such considerations of knowledge perspectives and construction are commonly referred to in the literature as “epistemologies” of the subject, of the teacher, and of the learner, an area of active research for several decades, and whose studies often tend to be linked to research and debates on the theme of the nature of science (NoS). My intent is not to survey and discuss the studies of the three epistemologies themselves, which would represent an informative Thesis in its own right (Lederman (2007), Abell (2007) and Matthews (1998a) have covered considerable ground here already), but to concentrate on school subject epistemology primarily and related debates in the nature of science as discussed in science education and philosophy of science. This will include referencing the valuable contributions on these themes from educators, philosophers and scientists involved with the History and Philosophy of Science (HPS) reform movement.

One suggestion of this Thesis is that a philosophy of science education informed by Shulman’s (1987) viewpoint would seek to influence science teachers’ specialist content knowledge (CK) through HPS awareness and education. With such broader and deeper HPS perspectives on their own disciplinary field(s) together with an acute
attentiveness to where curricular materials (especially textbooks) provide either grossly over-simplified or even erroneous views of scientists or the nature of science, teachers would be in a better position to present a more accurate and comprehensive view of science for their students. One can make this argument on its own grounds irrespective of educational metatheory, and it retains its validity regardless of which education system one happens to be working within, either the Anglo-American “Curriculum” tradition or the Continental “Didaktik” one. Moreover, as Fensham (2004) has been quoted earlier as stating, neither the former tradition nor the latter “problematises” the subject content to be learned, rather both have “held strongly to the idea that the content for school science subjects should be determined by what is accepted as lying within the content of the corresponding disciplinary science” (p.158). Teachers do not in general question such content either, or its assumed underlying epistemology, although the HPS reform movement has been addressing these inadequacies for some time now.

Even the use of an educational metatheory, I point out, whether Bildung or Egan, does not normally question the adequacy of the science content knowledge as typically presented by either state-mandated policy curricular documents or textbooks written by experts in their respective disciplines (secondary or tertiary). (These are the two primary sources, along with their own university academic science training, that teachers heavily rely on for planning and teaching). Recall that a metatheory serves the principal purpose of allowing for content transposition for educational purposes but leaves basically untouched the question of content knowledge adequacy—the fact that content as commonly presented is insufficient for a broader science subject understanding. As one critical commentator has stated: “The textbook as it now exists is necessary but not sufficient. The full flavour and excitement of science as a creative process cannot be
experienced in a historical and philosophical vacuum” (Brackenridge, 1989, p. 80). A PoSE serving as well as a kind of “Didaktik analysis” could then in addition critically examine both the common CK and the growing literature of HPS influenced research and curriculum materials for appropriate use in classroom pedagogy, thus contributing to develop a teacher’s pedagogical content knowledge (PCK). (To anticipate the last chapter, looking at this issue from a hermeneutic perspective, this would mean to allow the horizon of a teacher’s epistemology (or understanding of subject content) to expand through awareness of the need of nature-of-science (NoS) insight and HPS integration—the other horizon of significance, as provided by research—as an essential component of their pedagogical content knowledge).

What I am suggesting corresponds to Scheffler’s standpoint, who decades earlier had invoked the value of philosophy as a “second-order reflection” for science teachers to critically examine their practice (“to bring philosophical thought to bear significantly on educational practice”, 1970/92, p.385):

The teacher requires … a general conceptual grasp of science and a capacity to formulate and explain its workings to the outsider … No matter what additional resources the teacher may draw on, he needs at least to assume the standpoint of philosophy in performing his work … If philosophy of science is a second-order reflective approach to scientific inquiry, science teaching also incorporates such a second-order reflective approach. The science teacher needs to do other things than reflect on science, to be sure, but whatever he does is likely to be qualified by his second-order reflections on the field of science. Unlike the researcher [or philosopher] he cannot isolate himself within the protective walls of some scientific specialty; he functions willy-nilly as a philosopher in critical aspects of his role (p.389).

Duschl, in Restructuring Science Education, hints at PCK when he writes:

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107 Egan’s metatheory however, although neutral on this topic, does not exclude the use of HPS integration, as argued last chapter—nor for that matter, does it exclude concerns of STS reform issues—as long as these are integrated in such a way to further students’ cognitive-emotive tools as “romantic” or “philosophic” frames of understanding. As I mentioned, his distinctive “narrative approach” lends itself easily to historical “story-telling” in science class, as well as incorporating respective epistemological features. In other words, his argument for proper transposition can incorporate content broadening. This point could in principle also apply to the Bildung metatheory, but because it has been traditionally conceptualized more along exclusive humanistic lines (Eisner’s “rational humanism”), often in contrast to the conception and methods of the natural sciences and the way they are generally thought needed to be taught, it has tended to be conceptually and institutionally isolated from science education. In Germany at the gymnasiel (upper secondary) level the contrast is manifested in two different kinds of schools, humanistische (classics, literature and language focus) and naturwissenschaftliche Gymnasien (science school focus), where the Bildung paradigm is usually associated with the former only. Here the bifurcation of Western culture has been rigidly institutionalized.
Right or wrong, appropriate or not, a teacher makes numerous decisions on a daily basis concerning the design, delivery, and evaluation of instruction. An effective decision maker considers the learner, the learning environment, and the nature of the subject matter. The issue is a teacher’s ability to make informed judgments that eventually lead to meaningful learning on the part of students. A central component of this decision-making process is a teacher’s subject matter knowledge … To achieve such educational goals, the teacher needs to acquire a special type of knowledge base. In addition to knowledge of schools, learners, and teaching strategies [PK], teachers also need a special knowledge base of the structure of the subject (1990, p.2).

He argues such a base must include knowledge from the history and philosophy of science, requiring teachers to emphasize not only “what” is known (learning of science) but also “how” it is known (learning about science). Such a stand would mean a shift in the focus of science education, he insists, the need to overcome the “epistemological flatness” of “curriculum materials or instructional strategies that do not give a complete picture of the concepts being taught” (p.41).

The Swedish educator Tomas Englund (1998) drawing upon the situation in his own country has also criticized the “structure of the discipline” as a starting point for curriculum and the common approach for science teaching:

Whenever that happens, it becomes difficult to “problematize” the school science content; it is much more likely that it will be taken for granted. In such cases, the meaning that students are offered by their school subject—what I will call the educational content of school subjects—is always at risk of being dominated by a narrow view of the socialization function of education. This situation unquestionably is linked to the fact that the moral and philosophical aspects of education and socialization have been neglected (original italics; p.13).

Englund identifies the overbearing instrumental rationality characteristic of educational thinking and research as applied to the purposes of schooling as the predominant reason for this neglect, and this could be a reason why philosophy in general has been accorded such a low value, and perhaps why the need for PoSE has not come to the fore sooner. As argued previously, science education has always been burdened with the “socialization imperative”, which at times has taken on primarily utilitarian, even extreme economic tones (e.g. to educate for reasons of increasing the professional
'pipeline', or increasing national economic status, or increasing the critical thinking of citizens for judging techno-scientific claims in society, thus to enhance democracy, etc.

Problematicizing school subject content is a moral and philosophical endeavor that cannot be addressed by scientific-technical rationality. The central questions of philosophical inquiry in education are about the worth of knowledge and meaning offered to students. Scientific technical questions about efficiency and effectiveness are quite different questions—yet efficiency and effectiveness questions tend to be more prevalent than philosophical inquiry, on the educational research agendas of many countries (ibid).

He suggests that school subject content can be categorized at least three different ways according to how the educational significance is conceptualized (pp.19-20):

- **Epistemic (school subject) content**: determined “essentialistically and scientistically”. For science education this means the relation between a science discipline and the school subject in terms of how the knowledge is structured and how the key concepts (gravity, electricity, chemical bonds, genes, etc.) are internally inter-related to others in a formal conceptual web of scientific meaning (this I take as traditionalism).

- **Contextual (Awareness) content**¹⁰⁸: Here he seems to mean those relations of a subject as linked to other broader contexts “such as the relationship between the individual and society, individual and nature … dealt with, explicitly or implicitly, as educational content.” The non-traditional “curriculum emphases” of Roberts (1982; like “Self as explainer”, STS) as to how science epistemic content is (or should be) linked to other humanistic or techno-societal concerns and issues, can be placed here.

- **Socialization content**: “… includes the different meaning-creation contexts or discourses where different conceptualizations of the relation studied [contextual content] are expressed” (p.20). He means the justification of why a subject is required to be learned and the reasons for educating the individual (educational aims), and these tend to accompany what is taught (overtly or not) in schools as “companion meanings”. He lists “patriarchal, scientific-rational, or democratic” (one could easily add “colonialist”), and

¹⁰⁸ I have renamed his category labeled “knowledge content”, which is confusing and misleading. I interpret his intention to surface contextual factors, and he appears to take “knowledge” in the widest sense to imply an understanding where “epistemic content” is related to its contexts. One could perhaps have labeled it alternatively “Knowing content contexts”, but this is awkward.
indicates how science content is provided with an ulterior *instrumental meaning* according to its socio-cultural embeddedness and group “ideological” interests.

In the first category the content knowledge (CK) is taken as decontextualized and its “educational content” (or significance) is confined to formal knowledge acquisition which serves as its (restricted) academic *scientific meaning*. In the second case, the educational content is widened and understood to reside in the context in which the epistemic content can be situated, providing for *contextual meaning*. In the last case, the educational significance locates the contextual meaning of CK within the milieu of broader educational philosophical goals, policy decisions and group interests, marking its *socio-instrumental meaning* (as previously discussed in chapter 2).

Examining the last category, one immediately identifies the broader educational goals listed earlier, “scientific-rational” can be associated with the Platonic knowledge-based project, “democratic” with the intents of Deweyan-based educational philosophy. The point that Englund wants to make is that if curriculum is viewed in socio-cultural light, even the traditional “epistemic content” (his first category) of typical science classes must carry with it other associated or “companion meanings” as to the ultimate educational reasons why the material has value and must be learned, and teachers usually fall back on some sort of explanation when cheeky or exasperated students ask “why are we learning this stuff?” In other words, students usually seek meaning beyond the narrow academic-scientific one. “Knowledge for knowledge sake” as pure academic rationalism (Eisner) will rarely suffice, although the “scientific-rational” line of reasoning usually includes claims about learning “truths about nature”, or about “how things really work”, although the former assumes a clean objectivist-realist notion of science, and the latter harbours a simple science-technology link—both of which a more sophisticated science curriculum that include HPS and STS aspects would

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109 Englund himself references Dewey, and it becomes clear that this kind of socialization is the one he not only prefers but—along with the rest of the authors in the book and like-minded champions of the STS reform movement earlier—insists should be the overall educational rationale for science teaching and CK orientation. He would therefore take the main task of PoSE as I see it, to consist in “reestablishing the philosophical aspect of educational and didactic research” (p.23) along these lines and towards this end: “Thus the educational philosophy that has focused on the relationship between democracy and education is placed center stage” (p.24).
help debunk. That is, curriculum and CK taken as "contextual" and not just narrowly as "epistemic." One final reason usually given for "epistemic content" when arguing in "scientific-rational" mode for socialization is that mastery of such knowledge serves as a gateway to higher education and professional careers (often in engineering, medicine or pharmacy, possibly even science teaching), yet it is well known this applies only to a minority (approx. 15-20%) of students.

As can be seen, the companion meanings often implied\textsuperscript{110}, which are conveyed to students (overtly or covertly) with "epistemic content" have serious epistemological as well as practical significance—for along with the details of laws, concepts, scientific descriptions and processes learned in classrooms “they are taught what knowledge, and what kind of knowledge, is worth knowing and whether they can master it. They are taught how to regard themselves in relation to both natural and technological devised objects and events, and with what demeanor to regard those objects and events” (Roberts and Oestman, 1998, p.ix). Along with whatever attitudes towards science, knowledge, science learning and their own self-image (which in the case of physics we know is not attractive to many females) invariably associated with companion meanings, are the following regarding content knowledge (CK): that it is largely disconnected to either the students’ everyday lives or has little wider socio-technological purpose or implications; that strict adherence to learning decontextualized scientific knowledge (“epistemic content”) and its evaluation using standardized and high stakes testing is somehow representative of how scientific knowledge is generated (if not a mirror of the enterprise) itself; that mastery of such formal knowledge structures is sufficient and sole grounds for professional entry; finally, that CK logically structured is ahiistorical, objectivist and complete—and thus not historical, interpretive and tentative. The argument I wish to focus on here is the last point, that CK and the science curriculum common to schools is not epistemologically neutral.

\textsuperscript{110} I borrow this term from Roberts and Oestman (1998, p.ix): “We argue, broadly, that the “socialization” of students is not only a matter of their deportment, attitudes, conduct and so forth, as the term tends to be used, but is also very significantly associated with the meanings provided by their educational experiences. Science textbooks, teachers, and classrooms teach a lot more than the scientific meanings of concepts … Most of the extras are taught implicitly, often by what is not stated. Students are taught about power and authority, for example. … All of these extras we call “companion meanings” …” and they “function as both context and subtext for the more obvious subject matter meanings in school subjects.”
As a preliminary comment, it should be mentioned that content knowledge (CK) need not necessarily be construed narrowly as "epistemic" with its accompanying "scientific meaning" typical for traditionalism, although as the status quo this remains widespread at the upper levels for the case of senior physics, chemistry, geology and biology. It has been the explicit purpose of policy and curriculum developers as published in both American and Canadian Standards documents of the 1990s to move away from this conception and tight disciplinary structure to encompass broader contexts for this knowledge. It needs to be pointed out that traditional CK is supplied by several companion meanings formulated as three (of seven) "curriculum emphases" (Roberts, 1982): i) to build a "Solid foundation" (logic of subject topics in succeeding years), ii) to give "Correct explanations" ["products"], and iii) to ensure "Scientific skill development" ["processes"]. These three alone, and taken together, usually serve as mutually supporting rationales for teachers when inducting their students into academic science at the upper 11 and 12 levels. Opposed to this view, the conception of content in the Standards was purposely taken as broader than the conventional sense, as Bybee (1998, p.163) writes for the U.S. case:

The definition of content in the National Science Education Standards and the Benchmarks for Science Literacy is broader than "valid science" and Correct Explanations. To be sure, there is traditional content associated with physical, life, and earth science, but content is defined to include also the nature of science, technology, history of science, inquiry, and science in personal and social perspectives.

The Canadian Common Framework (Council of Ministers, 1997) also expanded the understanding of CK beyond traditional disciplinary "knowledge", which serves as only one of four "foundation" frameworks for specifying scientific literacy (the other three being STSE contexts, skills and attitudes). Unfortunately these kinds of documents only tend to have force at the lower levels and attempts to broaden the scope of CK outside of the confines of "epistemic" for 11 and 12 grades and specialty science courses simply has not happened—Denmark being an exception (Thomsen, 1998)—and actual cases of implementation efforts beyond strict "epistemic" in Alberta and Australia have even met with considerable resistance from external stakeholders (academic scientists,
media, parents; Orpwood, 1998; Fensham, 1998). As Bybee has expressed one pitfall of the reform efforts, a “narrow view” of CK continues to prevail among interest groups which disallow other interpretations (exacerbated in absence of educational metatheory, as argued). In truth, it should not be surprising to Englund, Bybee and others that an impasse often arises with the two differing “educational contents” or perspectives taken on CK, for the epistemic CK conception is customarily entrenched in a “scientific-rational” ideology (or academic rationalism, entailing its own companion meanings) whereas the contextual CK is often located within a “democratic-socialization” ideology of educational purposes and goals. The various stakeholders beholden to these two conceptions (or “visions” of literacy; Roberts, 2007) are themselves divided as to the chief aim of science education (expressed in utilitarian terms), either to educate persons in science for academic science (“science for future scientists”) or for democracy (“science for citizens”). We notice clearly once again how CK is equally and unavoidably tied to disparate educational ideas or philosophies (fixed as ideologies among stakeholders) identified by Egan as being at fundamental odds.

4.2. Philosophy of Science Education and Nature of Science (NoS)

My concern in this chapter is to concentrate on the epistemological companion meanings, those assumptions or perspectives that lie (often hidden) behind common science curriculum as they tend to inform student and teacher epistemologies, and how an improved understanding of the nature of science (NoS) among both can improve science teaching and learning. It probably goes without saying that any philosophy of science education (PoSE) which has as its main concern the education of persons into the disciplines of science (narrowly construed)—or better phrased, an education of the scientific enterprise (widely construed)—must consider what studies into the epistemology and nature-of-science have revealed and how this bears upon analyzing and critiquing subject content knowledge (CK). This means the need to canvas assorted

111 Other pitfalls he mentions are the “rush to closure” and “losing sight of constraints”. The former refers to how textbook publishers, local school districts and teachers could embrace the Standards in either a superficial way or pick-and-choose aspects in order to keep the “epistemic” content and traditional curriculum largely intact. This appears to have been the case with recent implementation efforts in California (Bianchini and Kelly, 2003). The second refers to constraints of the educational system such as incurred costs to districts (professional development; resources), also school culture and teacher attitudes.
discussions and debates pertaining to the general construal and generation of scientific knowledge undertaken in the academic disciplines of the history, sociology and philosophy of science. Such an undertaking it is understood at the outset, cannot be an exhaustive one for this Thesis, since these different fields of study as they have matured in the past half-century or so have accumulated a vast array of studies on different aspects of science and its separate disciplines showing a range of views and controversies, from realist and anti-realist views in the philosophy of science (Laudan, 1990) to full blown knowledge relativism as found in certain positions held by those in the “strong programme” of the sociology of science (Ogborn, 1995; Slezak, 1994a,b). An invaluable resource is the detailed review by Duschl in the (1994) Handbook, who had examined studies in the history and philosophy (but not sociology) of science as to their diverse contributions to educational developments in science education proper during the 40-year period 1950-1990, when major transitions took place.

My intent here is to broaden the definition of content (CK), as the Standards had hoped to do (and many of their HPS ideas and themes are invaluable), by arguing that although epistemic content is necessary it is hardly sufficient for education either in science or about science. Interest in studying the “epistemology of school science” have already produced several significant prior studies (Hodson, 1985; Cawthron and Rowell, 1978; Smolicz and Nunan, 1975; Elkana, 1970), and research continues into both teacher and student epistemologies (Abd-El-Khalick and Lederman, 2000; Désautels and Larochelle, 1998; Driver et al., 1996; Meichstry, 1993; Ryan and Aikenhead, 1992), but, sadly, such studies have too often shown that an improved alignment between teacher and nature-of-science epistemologies which several authors have recognized as of central importance is still far from being realized (Matthews, 1994; Duschl, 1990; Hodson, 1985).

In line with other reform efforts, my work should be seen as contributing to achieving those objectives as found in the Standards documents, with their explicit emphasis to include NoS instruction. They form part of a larger appeal for more fundamental changes in the attitude and approach to science teaching, as accentuated in the U.S. National Science Foundation Report (NSF, 1996) for undergraduate science education as well (Mason and Gilbert, 2004). The argument has been made that NoS
inclusion enhances the educative value by raising the interdisciplinary and cultural dimensions of science courses—since it embeds scientific development in cultural and historical contexts while fostering among students a greater emotional satisfaction of curricular themes. This all contributes ultimately to their better appreciation of science and understanding of the natural world (Matthews, 1994). Furthermore, a curricular stress on the inherent but too often neglected epistemological dimension could contribute significantly to a substantive improvement in content knowledge (CK) understanding. The science education researcher Norman Lederman (1998) having noted that science education suffers from “subject matter without context”, contends that unless NoS teaching is made explicit (“given status equal to that of traditional subject matter”) the science literacy of students and citizens will hardly improve, and thereto, I would add, neither can they develop a proper scientific mind-set.

Comments about terminology: nature of science, epistemology and ontology:

- *Nature-of-Science* (NoS): I follow Osborne et al. (2003, p. 717) in distinguishing between three distinct albeit inter-related components: i) nature of scientific knowledge, ii) methodologies of science, and iii) science institutions and its social practices. I will limit my discussion predominately to the first, a confined perspective on those distinctive features of science concerning its epistemology and ontology. The second is usually framed as “scientific inquiry” and occasionally confused with NoS, while the last is frequently subsumed under the rubric of the “sociology of science.” (I agree with Lederman that “nature-of-scientific-knowledge” and “scientific inquiry”—or more commonly “processes”—should be kept distinct, although they indeed interact and overlap).112 It is of course understood that both teachers and students need to develop an understanding of all three vital components, as several authors have come to stress (Driver et al., 1996; Shamos, 1995; Bauer, 1992; Hodson, 1991, 1985).

112 “Science processes are activities relating to collecting and analyzing data, and drawing conclusions. For example, observing and inferring are scientific processes. More complex than individual processes, scientific inquiry involves various science processes used in a cyclical manner. On the other hand, NOS refers to the epistemological underpinnings of the activities of science and characteristics of the resulting knowledge” (2007, p.835). See Schwartz et al. (2004) for a recent discussion on scientific inquiry.
• **Epistemology**: the branch of philosophy that studies the nature of knowledge, its scope, foundations and validity; it deals with theories of knowledge, distinctions between believing and knowing, and justification. *Scientific* epistemology is concerned with describing and ascertaining the nature of both the body of known scientific facts and theories (degree of certainty) and the production of new knowledge (i.e. scientific inquiry). *Personal* epistemologies are commonly taken to include individual beliefs, views and attitudes about a particular subject, hence they can be considered a “personal knowledge framework” (i.e. “what do you know about ‘X’, and why do you know (it)?”).

• **Ontology**: the branch of philosophy (metaphysics) that concerns itself with the most general questions of the nature of “being” and existence. Questions regarding *scientific* ontology are concerned with ascertaining the status (or validity) of the products of human creativity and imagination, especially scientific models and theoretical entities (e.g. electron; gene; species; black hole; etc.), as to their reality or merely useful (fictive) construct to solve problems and ‘fit’ experimental data (*empirical adequacy*).

Driver *et al.* (1996, pp. 16-23) have presented five arguments for NoS understanding, linked explicitly to increasing the science literacy of the public, which have now come to be widely acknowledged though not necessarily equally accepted in the science education community:

1) *utilitarian* argument: NoS is necessary for people to make sense of science and technological objects encountered in their everyday lives.
2) *democratic* argument: NoS is necessary for people to make sense of socio-scientific issues and partake of democratic decision-making.
3) *cultural* argument: NoS is necessary for people to appreciate science as a significant factor in contemporary culture.
4) *moral* argument: NoS is necessary for people to become aware of the norms and moral commitments of the scientific community (ideals of rationality, objectivity, social consensus, self-correction, etc.).
5) *science learning* argument: NoS is necessary since it supports successful learning of [epistemic] content.

I contend that not all these arguments carry the same force, and some are surprisingly similar to those earlier put forward in the 1980s for teaching STS, especially the first two, which have been refuted by Shamos (1995). Yet because there is a shift in focus to NoS comprehension rather than requiring competence in evaluating technologies and technological impact on society (where even the experts can differ over frontier
science and risk analysis, for example) the warrant for these arguments has changed and seems more reasonable (given the examples listed by the authors). That being said, my own immediate interest is aligned with the third and fifth arguments.

Notwithstanding such rationales, which are important when arguing for HPS and NOS inclusion in classrooms and for re-writing curricular materials, the empirical findings of the last 50 years allows for some generalizations which can surprise, disappoint and discourage science educators. Lederman (2007, p.869) concludes:

i) K-12 students lack adequate NoS understanding
ii) K-12 teachers lack adequate NoS understanding
iii) Teachers’ ideas of NoS are often not translated into classroom practice
iv) Teachers consider NoS a lower priority for instructional outcomes
v) NoS conceptions are best learned through explicit instruction

Lederman complains of inadequate measurement instruments in some research work (biased NoS notions among researchers) and the “superficial” nature of current testing strategies of NoS given the little known “mechanisms” that can contribute to changing teachers’ and students’ views. Indeed, the bulk of all this research work and perhaps its primary redeeming value seems to consistently confirm the same conclusions as listed above. One other discovery has been made: “The longevity of this educational objective has been surpassed only by the longevity of students’ inability to articulate the meaning of the phrase ‘nature of science’” (ibid, p. 832), a conclusion Lederman had uttered ten years previously. Considering how entrenched the conventional academic paradigm has become at precollege and college levels—which will be further examined below—one is only surprised that others are surprised at these results, for “science teachers and science curricula seem rigidly bound to a tradition of communicating facts or end products of science while generally neglecting how this knowledge was constructed” (McComas et al., 1998, p. 541). The argument that science teaching should also put emphasis on “how knowledge is constructed” is itself an old one, going back to Schwab (1962), Dewey (1916) and Mach (Matthews, 1991; DeBoer, 1991), and likewise one might add its longevity as argument has only been surpassed by the longevity of its neglect. The revived HPS movement has reiterated it once again.
Textbooks are not the sole culprits but they bear much responsibility: "for most science students, a description of the NOS is relegated to a few paragraphs at the beginning of the textbook quickly glossed over in favor of the facts and concepts that cram the remainder of the book and generally fill the course. And the ideas put forth in textbooks ... concerning the nature of science are almost universally incorrect, simplistic, or incomplete" (ibid, pp.14-5). Taking the inherent attitudes and epistemology of this paradigm with its curriculum and how it views and structures epistemic knowledge into account, on top of how science teachers are themselves educated, then the first four items listed above fail to astonish. If anything I would conclude that such results cry out for a fundamental shift in attitudes and thinking of what comprises science education, for real HPS reforms and available resources, and the absolute necessity of a "philosophy of science education" on the part of teachers and the discipline.

One more obstacle needs to be addressed, namely the charge that there is no agreement among the experts as to what NoS is and that because of this lack of consensus it is sheer folly to try to articulate NoS positions for teacher awareness and for student mastery:

... the fact of the matter is that we have no well-confirmed general picture of how science works, no theory of science worthy of general assent. We did once have a well-developed and historically influential position, that of positivism or logical empiricism, which has by now been effectively refuted. We have a number of recent theories of science which ... have hardly been tested at all. ... If any extant position does provide a viable understanding of how science operates, we are far from being able to identify which it is (Laudan et al., 1986, p.142).

Given this confusing situation three philosophers of science (Eflin et al., 1999) have come forward and offered some advice to the perplexed science educator. Much of what they suggest is indeed useful, including laying out: i) the common ground shared among philosophers as to what constitute the basic tenets of science\textsuperscript{113}; ii) what is not shared;\textsuperscript{114} and, more importantly, iii) the advice that educators must become more

\textsuperscript{113} They are: 1) The main purpose of science is to acquire knowledge of the physical world; 2) An underlying order exists which science seeks to describe in a maximally simple and comprehensive manner; 3) Science is dynamic, changing and tentative; 4) There is no single scientific method.

\textsuperscript{114} 1) There exists considerable dissensus over how the generation of scientific knowledge depends on theoretical commitments and social and historical factors; 2) There is dissensus over the 'truth' value of scientific theories (what they claim exist in the world) independent of the scientist and/or scientific community (i.e. social constructivism versus realism versus anti-realism).
familiar with the details of the controversies of the debate among philosophers, historians and sociologists—which is exactly of course, what HPS advocates stress. These polarized camps have made the business of science education a messy and complicated affair—it has become increasingly difficult to navigate a pedagogical course between competing views “from diehard realism to radical constructivism” (Rudolph, 2000, p. 404).

Rudolph (2002, 2000), having noted the disagreements among academics and the “vague generalizations” of typical Standards policy documents, is among a few thoughtful detractors insisting science educators should re-evaluate the usefulness of NoS statements and instruction. He argues that no “single nature of science exists” (he allows for pluralities)—referencing the “disunity of the sciences” debate and outlook (Galison and Stump, 1996)—and even if one did at best only a simple and “partial representation of it could ever be captured in the school experiences designed for students” (2002, p.65). But this would unavoidably involve a selection process, he continues, raising questions about omissions and the decision-making process that is invariably linked to external socio-political factors and reasons and thus must be further justified on these same grounds. Given that the epistemology of science has always been subject to selection for socio-political reasons when constructing curriculum (he cites Dewey and Schwab as past cases), there is no reason to ignore this fact, and therefore the task of educators is to first choose the appropriate social ends they think worthy and then tailor their NoS selection accordingly. This is in essence an argument to subordinate NoS to the socialization imperative, to submit the construal of the image of science to serve public policy or other socially determined ends. A kind of argument, I might add, that falls square into the territory of a philosophy of science education that must be willing to

115 Current science education, however, at the undergraduate level (the background of most science educators), and pedagogical training of science educators in education faculties have both tended to ignore this, as mentioned before. Nor has this awareness penetrated the institutions responsible for training scientists or science teachers, both of whom chiefly obtain their understanding of science from formal, textbook-dominated lessons and “cookbook” laboratory exercises.

116 Rudolph (2000) has suggested that the nature of science debate has only tended to expose more heat than light, and hence the science educator should side-step issues attempting to pin-down what a universalist, covering methodology or aims may be, for a particularist view of diverse methods and goals specific and unique to each discipline. This should include sidestepping the common philosophical questions of science’s ultimate aims (axiology), where there continues to be little agreement (“Does science aim at truth or merely aim at empirical adequacy?”), for a narrow focus on context and practice (and also truth) as found within the specific discipline and group of practitioners. Although this advice may indeed remove NOS out of the vague context of Standards documents, it does little to help the educator elaborate discipline-specific NOS and the questions of truth that inevitably arise there (e.g. in physics).
engage with it. One role for a PoSE could certainly be that of constructing an image of
science from a grab-bag of selected NoS tenets commensurate with specified social ends,
although I would personally dispute that project.

I acknowledge the challenge but recognize the limitations of this current Thesis. Nonethe-
less, there is some merit to his claim fronting the disunity thesis as well as the
fact that the epistemology of science has been selected to serve social ends before. My
position as articulated in this Thesis is that neither education nor epistemology should be
subordinated to socialization, regardless of previous cases. That is not only to disagree
that such cases must be taken as precedent setting, rather that epistemology must be
taught and learned for its own sake, and most importantly, must serve as a corrective to
supplant a mistaken epistemology (and history) already existing. And one can disagree
that a selection process must always be linked socio-politically (and not philosophically,
logically, educationally or pragmatically, say). Moreover, it seems that his position
hinges chiefly on the view that NoS tenets are so fragmented and diverse that a pick-and-
choose type selection is unproblematic. This nominalist view (shared by many
sociologists of science) can be contrasted with the essentialist view, holding to a more
singular view or template, an ideal of science that can be gleaned and articulated as a
somewhat more “unified” nature-of-science notion (Matthews, 1998a). On this dispute
the jury is still out. Further, the answers to the dilemma are also relative to whether one
takes a more internalist (epistemic) or externalist (sociological) perspective on the
question, or possibly hazards a combination of both, as some contemporary philosophers
of science like Haack (2003) and Giere (2005), or cognitive psychologists like Nersessian
(2003) have articulated. (See here also Duschl and Hamilton, 1998). Both perspectives
are essential to understand scientific development and should be taken as complementary
and not contrary.

Most science educators notwithstanding grant his point about “partial
representation,” are willing to live with this and content to articulate a common list of
essential NoS theses (see below) where broad agreement does exist and where their
“generality” need not detract from genuine insight and understanding about the scientific
enterprise (Lederman, 2007; Osborne et al., 2003; McComas and Olson, 1998). One can
accept a range of NoS clarification, from more general to more sophisticated articulations
depending upon the course, grade and learner age-developmental stage. I see this spectrum encompassing the list below, as a bare minimum, to more elaborate epistemological frameworks (Duschl, 1990), to still more erudite discussion, such as the realism/instrumentalism controversy.

1) Empirical basis: scientific knowledge is based on observations of the world
2) Observation and inference: the senses and extension of senses give us information; Inferences are interpretations of observations.
3) Methodology: there is no one step-by-step scientific method; science relies on experimental evidence, rational arguments, peer review and skepticism.
4) Laws and theories: are different kinds of scientific knowledge. Laws describe relationships of phenomena, while theories are inferred explanations. They do not progress into one another.
5) Subjectivity: current theories and laws influence investigations and observations. Observations are theory-laden. Personal values and agendas also influence how scientists work.
6) Creativity: scientific knowledge is created from human imagination and logical reasoning, and based on observations and inferences.
7) Tentativeness: scientific knowledge is durable yet subject to change; science historically exhibits both evolutionary and revolutionary changes.
8) Socio-cultural embeddedness: science is part of social and cultural traditions, and scientific ideas affect, and are affected by, this milieu.
9) Applied science: science and technology are different but impact each other.

Probably all can agree that these points are at a level of generality such that they can be immediately communicated to teachers and inculcated in students. While this is true and helpful, regrettably it is exactly this generality, alternatively, that can mask the need to expose other essential aspects of NoS. One notices the failure to explicitly mention induction or inference to the best explanation (as key reasoning tools) and the neglect of the important role that models play in science and in reasoning—indeed, the need to distinguish theories from models—and hence, an avoidance of any mention of the status of theories or models as realist or instrumentalist (realist/instrumentalist debate). Also missing is the notion of the underdetermination of data (Duhem-Quine thesis). These are, it seems to me, serious omissions which need correction. Such important facets need not be avoided (see Holton and Brush, 2001, on the Duhem-Quine thesis, and Matthews, 1994, on the realist/instrumentalist debate; also Section 4.6).

4.3. Kuhn, Schwab and Siegel on Science Education and Textbooks

Thomas Kuhn (1970)—the great revolutionary himself—had ironically remained very conservative on the matter of HPS integration, and argued openly for the retention of the mythical historical picture of the textbook presentation of science, its practitioners,
its inquiry and its epistemic content knowledge (CK) as typically found in the conventional paradigm. He stressed its value in upholding this ideal for the training of young competent "puzzle solvers" in advancing what he called "normal science" of the day. The textbook plays a fundamental and conservative role in this objective, and helps reinforce the dominant (dogmatic) paradigm. Successful science as conducted by most scientists most of the time, he argued, is primarily about preserving that paradigm and maintaining the social consensus around it—and rarely about pushing boundaries into new territory that could lead to a conceptual revolution and a new paradigm (although this sometimes happens, and its preconditions—in opposition to Popper's views—are mainly non-rational; pp.138-43). Kuhn even readily admits that such a textbook centered pedagogy stifles imagination and innovation.117 As a physicist and historian of science he has been among the few in his day to have shown not only an interest in science education (marginally improved today, largely due to the HPS movement; Holton, 2003), but to have commented on its vital role in the training of scientific minds: "... science education remains a relatively dogmatic initiation into a pre-established problem-solving tradition that the student is neither invited nor equipped to evaluate."118

Siegel (1979) has criticized this educational approach described by Kuhn as dishonest, irresponsible, and cognitively restricting—and so an altogether unsatisfactory pedagogy, which I believe is correct—although Kuhn, as an insider (physicist), should be given credit for portraying how the scientist-discipline centered (traditional) paradigm (entrenched since the 1950s reform) actually seems to think it should educate—certainly this belief holds sway in all first year undergraduate introductory courses. Stinner (1995b; 1992) argues, moreover, that in classrooms at the upper levels Kuhn's insights degenerate into the de-contextualized problem-solving techniques now identified to be at the heart of the problem of context (as discussed previously).119

117 He wrote that in general: "scientific training is not well designed to produce the man who will easily discover a fresh approach" (Kuhn, 1970, p.166). In other words, it cannot help to generate new creative ideas which will contribute to resolving 'puzzles' within a domineering paradigm or even possibly initiating scientific revolutions (or "shifts in paradigms")—the two different ways that Kuhn understood 'progress' could occur in science (though he insisted 'revolutions' were rare events in history of science).

118 Quoted in Siegel (1978, p.302). See here also Kuhn (1977, p.229) for an earlier, almost same statement.

119 He emphasizes that "textbooks imprison science teachers in a belief that the instructional sequence of assign, recite, and test is guaranteed to produce knowledge" (Stinner, 2001, p.324). He adds: "For the majority of students, I maintain, doing problems is to memorize 'scientific facts' and practice algorithms" (1992, p.4; italics included).
It is precisely because of the reality of this problem that, exactly contrary to what Kuhn holds, "education" understood as training in "problem exemplars" in order to become efficient 'puzzle-solvers of normal science'—typical for both physics and chemistry classes—does not equip the aspiring young scientist for proper and successful scientific research work, and hence even less, give the general student a conceptual understanding of science—in large measure because such problems are ahistorically formulated, highly abstract and usually artificial.\(^{120}\) Kuhn's paradox, which he recognized, that the rigid training in solving artificial problems should somehow prepare the novice practitioner for engaging the kind of authentic problems scientists encounter in research, has been resolved by studies of student learning in Physics Education Research (PER): there is no paradox because he is simply wrong. Rather it is primarily—though not exclusively—through scientific apprenticeship (mentoring) at the graduate level that the young scientist becomes equipped for doing research while learning the norms and habits of the scientific community of which s/he is a part—a predominately socio-linguistic dimension.\(^{121}\) Kuhn was certainly aware of this aspect and included it as the vital second component of training for 'normal science' (1977, pp.229-30; 1970, p. 47). But the general science student is clearly at a severe disadvantage, even those specialized at the baccalaureate level and not continuing on, when it comes to perceiving what science is about and the haphazard nature of true research work. As Matthews observed: "Karl Popper said of Kuhn's normal scientist that he has been badly taught, that he has technique without understanding" (1988, p.70). Would only that such an assessment were more widespread among senior science classroom instructors. On the whole, however, Matthews indicts the science education community for its overhasty and uncritical acceptance of many of Kuhn's central ideas [paradigms; meaning variance;

\(^{120}\) "Without wishing to defend the excessive lengths to which this type of education has occasionally been carried, one cannot help but notice that in general it has been immensely effective. Of course, it is a narrow and rigid education, probably more so than any other except perhaps in orthodox theology. But for normal-scientific work, for puzzle-solving within the tradition that the textbooks define, the scientist is almost perfectly equipped" (Kuhn, 1970, p.165-166).

\(^{121}\) "Although Kuhn is right in pointing out that there is an "essential tension" between innovation and tradition, what he failed to appreciate fully is that it is mitigated by the flexibility in the apprenticeship learning component of training practitioners. Cognitive science research indicates that there are no paradoxes with respect to the traditional pedagogical method. The textbook-type science education has not been successful in producing practitioners. Very few students learn the subject sufficiently well even to provide explanations and predictions of simple physics phenomena, never mind to go on to graduate school and become practitioners" (Nersessian, 2003, p.189; original italics).
incommensurability; non-rationality; anti-realism, etc]: “there has been little prolonged engagement with his writings, and even less prolonged critical engagement” (2003a, p.112).122

Even if we decide to accept Kuhn’s popular account of the division of science into ‘normal’ and ‘revolutionary’ stages as a true descriptive account (which some philosophers such as Toulmin question, preferring instead “micro-revolutions”), and equally accept his view of current academic science texts as basically puzzle-solving, paradigm-fxated training manuals, we need not accept his or others’ prescriptive conclusions which seem to follow from them. Such as, because the average science student or would-be scientist will never be of a caliber to initiate a conceptual revolution (a la Newton, Lavoisier, Darwin or Einstein), our role as educators can be limited to, and quite satisfied with, training students solely for the ‘normal science’ of (the prevailing paradigm of) the day (or as is usually the case, of the past). This does indeed seem to be one pertinent feature of current traditional/textbook pedagogy, and reinforces the pseudo-historical view, one among many, that science progresses because of a “list of successive solitary geniuses”.123 Such an unfortunate perception on the part of students easily leads to feelings of inadequacy, that they are not able to contribute to science, and reinforces their alienation from the sciences (negatively referred to as the “mystique of science”, by Lemke, 1990).

A different perspective for science education is given by Schwab (1962), a well-known biology curriculum reformer. According to Siegel (1978) he appears to hold a similar picture of Kuhn’s two-fold division of the scientific enterprise, what he terms “stable” and “fluid” phases, and equally views the former as dogmatically inclined, yet he nonetheless reaches quite opposite conclusions. For Schwab, the orthodox and dogmatic

122 “The science education community is as guilty as any other of the charge of misunderstanding Kuhn, and drawing relativistic and subjectivistic epistemological conclusions” (ibid, p.112). This charge, for example, can be made against Nadeau and Désautels (1984) and Roth and Roychoudhury (1994). For a recent critique of Kuhn from a sympathetic commentator see Bird (2002). Previous critiques are McMullin (1993), Laudan (1984), and the collection in Lakatos and Musgrave (1970). Siegel (1987) has critically analyzed Kuhn’s and Feyerabend’s epistemological relativism, including their incommensurability thesis.

123 An evaluative review of standard physics textbooks in the 1970s/80s (Lehrman, 1982) had shown that almost all are poor when presenting historical and philosophical dimensions of science. Their value for technological applications was generally better, but even this was uneven. Since then improvement at least when it comes to technology has been better, see text by Cutnell and Johnson (1998), but it entirely ignores HoS. One notable exception for HPS has been Hecht (1994). But the text by Holton and Brush (1972/2001) represents the most comprehensive attempt to reshape a college physics textbook using HPS themes.
‘stable’ science is to be overcome by critical inquirers who consciously question and wish to push it into a ‘fluid’ phase—quite unlike Kuhn, where instead they are (and should be) transfixed instead by the controlling paradigm of ‘normal science’, only to be reluctantly pushed forward when shocked by irritating anomalies. Science education should then be about creating not competent puzzle-solvers but competent fluid enquirers, and textbooks are not about indoctrination into ‘normal science’ but rather an initiation to question and challenge the limits of ‘stable’ science (precisely what Kuhn argues strongly against, partly because they are not equipped to do so).

Schwab was quite correct when he emphasized that the traditional curricular focus on formal (content) knowledge at the expense of an emphasis on proper scientific processes and developing critical inquiry habits (as Dewey had emphasized) is to seriously misrepresent the nature of science as a “rhetoric of conclusions” (1962, p.24), which is how most textbook presentations can be caricatured. The scientific enterprise does indeed encompass both “stable” and “fluid” aspects, but I would not characterize these two as synonymous with Kuhn’s ‘normal’ and ‘revolutionary’ science phases, as Siegel (1978) does. This is a fundamental misrepresentation. Although I believe there is much historical evidence to commend Kuhn’s division (in other words it appears to be a reasonably accurate portraiture per se), it is because of his analysis of ‘normal’ science that I believe it can lend itself to a further division into ‘stable’ and ‘fluid’ phases in a way which still does justice to Schwab’s depiction of science—where both occur simultaneously (see also Elkana, 1970). Many other commentators have stressed this dual character in similar ways, contrasting ‘finished science’ from ‘science-in-the-making’ (Sutton, 1996), or ‘textbook’ versus ‘frontier’ science (Bauer, 1992), or even ‘public’ versus ‘private’ science (Martin et al., 1990; Elkana, 1970). All attempt to capture the actual two-fold nature of (pure) science as: i) a finished end product (of ‘declarative’ or ‘expository’ or ‘systematic’ knowledge) as found in handbooks or textbooks (but not as found in professional research journals), and ii) the essence of scientific research and inquiry; the former being static and the latter more dynamic in nature.

124 These discussions always refer to “pure” or “basic” and not “applied” science. It is interesting that Kuhn admitted that for the latter (and for inventors) his ‘normal/revolutionary’ distinction may not hold, nor his emphasis on textbooks as puzzle-solving initiations into normal science (Kuhn, 1977, pp. 237-9).
The exciting and open-ended ‘frontier’ aspect of (“normal”) science can lead to a Kuhnian-type revolution, but it need not, and in fact in most instances it does not. The relevant point for science education, however, is that this ‘frontier’ aspect is usually ignored in traditional pedagogy and thus an unduly distorted or excessively one-sided representation of science (NoS) must result. Furthermore, a proper historical treatment could spotlight the atypical yet decisive revolutionary character of science (Rogers, 1982), which both general science learners and aspiring scientists need to know.

From a pedagogical perspective, as Siegel argued, there is an even more serious charge against Kuhnian-type talk of dogmatic training for “normal science” education: authoritarianism. This can indeed be an unfortunate side-effect of how instructors present science, and traditional pedagogy seems particularly susceptible to this charge, where students must accept with a sort of ‘blind faith’ the claims of the textbook or the teacher. Even laboratory exercises (as personal experience of “scientific inquiry”) can be seen as special instances of ‘cooked’ examples to merely reinforce the claims previously presented in class—as is regrettably too often the case: a kind of weak indoctrination (Harris and Taylor, 1983). As Rogers (1982) has made clear, to avoid this accusation, the student’s confidence in the teacher and textbook as authority is only justified if the grounds are made explicit as to the reasons and inquiry processes which stand behind scientific knowledge, and from which its authority derives. (He held that a presentation of history could achieve this, allowing a balance between mere content knowledge and experimental work, extending ‘knowing that’ with ‘knowing how’.)

125 Laboratory work, often construed as helping students acquire technical skills, scientific reasoning and a glimpse of research work but which mainly is comprised of ‘cookbook’ type experiments combined with a simplified neo-Baconian inductivism can hardly be judged as a mirror of actual research, according to Hodson (1996) and others. Hence the renewed call for “authentic science inquiry” (Schwartz et al., 2004).

126 Kuhn’s insights on the nature of science education admits as much, especially concerning how readers of textbooks can be misled into thinking that applications of a theory as given in exercises confirm evidence of the theory—a typical pedagogical ploy! “But science students accept theories on the authority of teacher and text, not because of evidence. What alternatives have they, or what competence? The application given in texts are not there as evidence but because learning them is part of learning the paradigm ...”(1970, p.80)

127 Again, in agreement with my view that it allows for ‘knowing why’: “Unless the enabling and justificatory connection of process with knowledge-claim is made clear to the pupil, he can strictly have little rational ground for confidence in the educational enterprise; in no other way can the conditions upon which his knowledge-claim rest, give him ‘the right to be sure’” (p.3). Duschl (1990) would agree and has provided just such justificatory historical-epistemological frameworks for education. Rogers insists though that laboratory based-inquiry must be more genuine. He also freely admits that all ‘knowing that’ (expository) and ‘knowing how’ (experimental) aspects of science are conducted within a conceptual
Duschl (1988) accused the traditional paradigm of harbouring a ‘hidden positivist epistemology’ which is then inculcated into students, yet this is overdrawn. Although curricula could display aspects of such an outdated epistemology, and some do, it seems that textbooks in general show no such sophistication. It would be helpful if they did, because then one could much easier identify their implicit philosophy of science. Instead they often present an amalgam of confusing, sometimes contradictory positions with respect to POS topics.

The following represents only a small sampling of typical textbook cases. Harris and Taylor (1983) noted, for example, that the American PSSC physics (hard core traditionalist) mixes a simplistic inductivist view of methodology (which has been roundly criticized) with a naïve realist ontology, in its interpretation of models and theories for atoms and molecules (for example)—a departure from a pure positivist (instrumentalist) position. And it mixes theoretical constructs (model) and observational objects in the same way that actual working scientists do—not surprising because PSSC was developed by scientists during the 1950s reform wave. In other words they make the cognitive slide with ease across the theoretical construct/observable object divide—a controversial move that engenders considerable debate in philosophy of science. This observation cannot be emphasized enough—it constantly presents itself in typical textbook writings, and, so I maintain, is the major contributing factor to students’ naïve realist conceptions. The British Nuffield physics also shows such inconsistencies, and its misguided empiricist-inductive ‘discovery-inquiry approach’ is unmasked in reality as a teacher and curricula manipulated exercise (also critiqued by Hodson, 1996). Sometimes the same (historical) experiment is used to confirm a theory (i.e. validation; PSSC), or to introduce the theory (i.e. inductivism; Nuffield). In the latter case pupils can ostensibly “discover” the theory on their own (naïve inductivism). Both curricula suggest Newton’s laws can easily be inferred by students as generalizations from observations with experiments using “blocks and clocks” (inductivist thesis; “blissful empiricism”), which is patently false. For some curricula, such as historical-based Harvard Project Physics

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framework determining the kind of questions asked, what counts as evidence, and the nature of inquiry itself (as with Kuhnian “paradigms”).

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(HPP), popular in the 1970s, the authors identified hypothetico-deductive explanations, which they saw as consistently Popperian. Popper of course, is hardly a positivist.

Chemical textbooks I have examined (also physics texts) usually entail a naive falsificationist stance, the view that a “crucial experiment” refutes a theory, rather than merely a hypothesis (Hebden, 1998).\footnote{Popper’s falsificationist thesis (that no theory can ever be proven true, or probably true—contra logical empiricism—but can in principle be falsified) had been critiqued by many philosophers of science, including Kuhn and Feyerabend already in the 1960s (Lakatos and Musgrave, 1970). Today most consider his thesis “dead”. Much earlier, at the turn of the century, the French historian Pierre Duhem had explicitly attacked the view of the “crucial experiment” as an apparent decisive instance when rival theories in physics are compared (Duhem, 1954). His ideas today form part of the so-called “Duhem-Quine thesis” which argues, in part, that theories can only be tested as a whole, as a combined set of hypotheses, laws and background assumptions (Holistic thesis). Hence the empirical data always remains inconclusive, that is, neither truth nor falsity of a theory can be determined by evidence because auxiliary and ad hoc hypotheses can always be imagined (or invented) to “save” the theory (Underdetermination thesis). Curd and Cover (1998, p.255) admit that “probably no set of doctrines has had a greater influence on modern philosophy of science than those included under the designation of the Duhem-Quine thesis”, although one must be aware that “... an astonishing variety of doctrines fall under [that] umbrella.”} Earlier, Robinson (1969) argued that from the language patterns of biology and chemistry textbooks he analyzed students could be presented with alternately a realist or instrumentalist conception of theoretical entities. Munby (1976) also found this (the significance of language will be explored more in Chapter 5). Again, it is only the latter which corresponds with the classical logical-positivist or -empiricist position. Selley (1989), commenting on the revised Nuffield physics and chemistry texts for upper grades, noted little overt philosophical discussion, except for the occasional hypothetico-deductive and naive-falsificationist arguments. He concludes that “most school science books are utterly unsceptical” and that “the information and explanation being presented is simply the truth” (p.29). In the same vein as Robinson he holds that the “confident, assertive style” of the text passages could be read as implying either a naive realist metaphysics or a positivist-type instrumentalism. Gallagher (1991, p.123) along with Selley also finds that texts present the body of scientific knowledge as “revealed truth”, with “little attention given to the nature of science, or to how the knowledge of science is formulated or validated.” Science can be portrayed to varying degrees “from empirical to positivistic to Kuhnian” (p.124).

One wonders how science teachers who are usually uninformed about POS can be expected to navigate such interpretively vague, conflicting and even dogmatic assertions as normally found in their textbooks. Moreover, one should then hardly be surprised to
find teacher’s preconceptions of NOS and philosophical issues of science equally contrasted, clouded and confused, since they tend to rely heavily on their textbooks (McComas et al., 1998; Hodson, 1993b; Gallagher, 1991). Thereto, it hardly surprises that students exhibit a range of epistemological commitments, some even holding to inconsistent and contradictory views, such as mixing “objectivist” with constructivist-relativist views of knowledge (Roth and Roychoudhury, 1994, p.17).

More to the point, and given this typical situation in contemporary science education, the question as to what kind of philosophy of science would properly characterize science and should best be transmitted to teachers and students, and hence would help reform curricula and textbook writing, has certainly not been answered. To just continue with what has been done in the past, to ignore or pretend POS is irrelevant is obviously not an option. Clearly, ‘history’ and ‘philosophy’ are already “inside” textbooks and the curriculum but not in a form that provides authentic views (Niaz and Rodriguez, 2001; Allchin, 2000). Then again, surely not just any philosophy of science will do, for there exist several and they are contested (Ladyman, 2002; Nola and Sankey, 2000; Curd and Cover, 1998). At one extreme end, for example, Feyerabend’s “anarchistic philosophy” (1975) has polemically suggested that science is not served by any one method—frankly asserting “anything goes”. (Feyerabend, being quite critical of “Western science”, has also led the philosophical charge for anti-realism, and especially epistemological and cultural relativism). But a multitude of methods does not mean no method, nor that all are equally valid (Nola and Sankey, 2000).129

Should precollege and college instructors continue to accept and be satisfied with their roles as Kuhnian-type science educators—to train students to become ‘uncritical, competent puzzle-solvers of normal science’ with the sole professional ‘aim’ in mind?

The physicist Fritz Rohrlich (1988) has argued, contrary to Kuhn, that for an adequate understanding of science at least four philosophical issues about the nature of

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129 Nor are all knowledge claims scientific knowledge claims, nor yet, are all such cultural knowledge claims when conflicting with Western science equally valid and acceptable (Matthews, 1998a; 1994). Such important critical socio-philosophical issues arising from postmodernist critiques, from “cultural” and “social studies” of science, from the “science wars” debate—and taken together slowly starting to impact the values and identity of science education—cannot be addressed and critically appraised here.
science must be addressed in science education, and likewise these are indispensable for the training of scientists.\textsuperscript{130}

The absence of HPS in the curriculum has also been typically justified with the view that science education should distinguish between the “context of discovery” (or development) and the “context of justification”—a misapplied positivist principle—and privileges the latter over the former. In other words, the discipline is more concerned with “what is known” (knowledge as a finished product) than “how” or “why” it is known (knowledge as discovered and/or constructed, and theories as tentative). The bulk of textbook organized knowledge (including its language, Sutton, 1996) and traditional instruction reflects exactly this prejudice (Schwab and the “rhetoric of conclusions”). This state of affairs is clearly unacceptable (Duschl \textit{et al.}, 1990, p. 239):

Precollege science education curricula should address not only what is known by science, but should also include how science has come to arrive at such knowledge. To teach what is known in science is to stress declarative scientific knowledge. To teach how the scientific enterprise has arrived at its knowledge claims is to develop declarative and procedural knowledge of scientific developments. Knowledge of scientific development as opposed to scientific knowledge, then, is knowledge of both why science believes what it does and how science has come to think that way. In the distinction between scientific knowledge as a curricular objective, and knowledge about scientific development as a curricular objective, it is that the latter is more inclusive. This is the distinction between learning science, and learning about science.

4.4. Epistemology, HPS and Student Learning Theories

Duschl (1994) comments that HPS studies have had the general effect of influencing the conceptualization of both curriculum design (“what to teach”)—which is my predominant focus—and instructional practices with their learning models (“how to teach”)—which I have come to treat with a large measure of skepticism. I will briefly examine the second topic to start with.

On this latter point, one should perhaps begin on a note of caution, that identifying epistemological positions in either textbooks or of teachers is complex and

\textsuperscript{130} These include: 1) the invention-discovery (or theoretical-empirical) distinction; 2) the justification (criteria) of accepting a theory; 3) the question of the status of scientific theories (instrumentalism; levels of realism); 4) the role of epistemology.
challenging to carry out. Moreover, Smolitz and Nunan (1975) had warned some time ago in one of the earliest reviews examining the “philosophical and sociological foundations of school science” that philosophical investigations of science may not lead to helpful inferences where “educational directives” can be generated. “The relationships and interactions between the image of science, the philosophy of science and science education are indeed complex” (p.103). With respect to the influence of epistemology on learning models, that advice has not stopped efforts of several subsequent researchers, cognitive scientists like Carey (1986) and Nersessian (1992; 1989), nor science educators like Posner et al. (1982)—with their influential conceptual change model based on Kuhn—or even Duschl’s (1990) elaborate alternative epistemological model of science learning based on Laudan, to draw out exactly those kinds of educational learning directives.

These attempts to use epistemological models of science for explaining student learning processes I claim are misguided (whether based on Kuhn or Laudan in the past, or lately on Giere, as Izquierdo-Aymerich (2003) now argue) because they confuse learning the nature of science (NoS) with the nature of learning science (NoLS), (although as subjects they may indeed be related). This seems to me to confuse epistemology (as to what it can offer) with educational metatheory and how students come to know and make meaning. For if learning truly comes about through narrative then the nature of learning science (NoLS) is best explained by Egan’s metatheory (acquisition and use of cultural/cognitive tools that engage the imagination) and not analogies drawn from philosophy of science cases, which in themselves are subject to much continued dispute. And if language truly plays a central role (as many are coming to believe) then Gadamer’s (1975) insight of how “understanding” takes place, proceeding as an “expanded horizon” carried by students’ “interpretive narrative frameworks”, then conceptual change can be viewed from an entirely different and perhaps more fruitful perspective. NoS theories should therefore not be taken as a model for learning science, rather as stated, solely as a way to improve and expand both teachers’ and students’ content knowledge (CK), because learning the epistemology of science should be a content goal in its own right. To disagree that epistemology should substitute for educational theory is to part company with Duschl on this point (“the
inductivist" (p.33), as is typically displayed in the Baconian-type, step-wise linear
"scientific method" starting from naked observations, leading by inference to inductive
hypotheses, to general laws and objective knowledge. They hold that Popper’s
hypothetico-deductive, falsificationist philosophy of science has been “little studied by
science teachers and educationalists” and that “no clearly defined Popperian tradition
exists in school science” (p.36). They argued that the reason for the dominance of
empiricist-inductive view (despite Popper’s clear rejection of it) was due to the success of
“discovery learning” at the time which appeared in the 1950s and overlapped with
“science as an inquiry approach” (Hodson, 1996). This was endorsed by Schwab (1962),
psychologists and the new reforms being instituted “top-down” by state ministries and
scientists in the wake of the “Sputnik shock.” As they wrote: “It all seemed to fit; the
logic of knowledge and the psychology of knowledge had coalesced under the mesmeric
umbrella term ‘discovery’ and there was no very obvious reason for educators to look
further than the traditional inductivist-empiricist explanation of process” (p.38). The
irony being at the exact same time Kuhn and several others were heralding a new radical
post-empiricist phase in the philosophy of science. They note though that Popper had
reinforced the older view by also having emphasized one method for science (his
alternative hypothetico-deductive one) and assuming that both theories and their
empirical consequences could still be discriminated by use of a “neutral observation
language”. “That such a neutral language is taken for granted by school science texts is
... abundantly apparent” (p.38). Along with this mythical image of method have come
accompanying distorted images of science—its inevitable progress linearly forwards and
closer to truth (termed “convergent realism”)—and of the scientist as the individual
heroic explorer guided by the search for truth or “objective knowledge” (p.42).

Hodson (1985, p.27) likewise criticizes the legacy of inductivism (“long since
abandoned by philosophers of science”) and its role in perpetuating the myth of one
dominating “scientific method”. This myth, singled out and heavily criticized in a book
by Bauer (1992), still tends to be widespread. Likewise, I have discovered the paradox
that while the latest Canadian junior science texts often avoid this term and talk of
general scientific “processes” (observing, hypothesizing, modeling, etc.) that students
need to learn, too many senior specialist science texts still refer to this phrase. Hodson

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also comments on the inconsistency of British curricular materials of the day, some employing an inductivist outlook (*Nuffield Chemistry*) whereas others (*Nuffield Physics*) explicitly reject it (p.35). These glaring inconsistencies in curricular materials, mentioned earlier, make the identification of an inherent *single* epistemology difficult.

When examining the critics, however, it becomes apparent that "method" is usually interpreted in science education in different ways, and the step-wise inductive method discussed by Cawthon and Rowell (1978) is at odds with Duschl’s (1994, p.444) identified *hypothetico-deductive step-wise method*: 1) select hypothesis; 2) conduct observations; 3) collect data; 4) test hypothesis; 5) reject or accept hypothesis. This certainly appears (in highly simplified form) more akin to Popper’s (1963) procedure of science progressing by "bold conjectures and refutations." There is also a clear resemblance here with Dewey’s own description of "scientific method" as problem-solving (1916, pp.152-163), taken as problem, hypothesis generation, testing and application (with the caveat it should be practical oriented and situated in the student’s immediate social environment). I admit that science textbooks and classrooms often can emphasize observations and structure laboratory inquiry in an inductive-verificationist mode (akin to 1950s logical—positivist philosophy) or imply scientific knowledge grows predominately in this way (which is fallacious)—this occurs when *theories* and finally *scientific laws* (which are erroneously thought to develop from them) are described as easily proceeding from data or "careful observations" and then "proven". Such language is indicative, certainly, but I believe Duschl more on the mark when he states that hypothetico-deductivism is characteristic: “science teachers would immediately recognize [this] as the standard scientific method.” Teachers often ask a student to “prove your hypothesis right or wrong”, and this procedure furthermore is on occasion mistakenly thought to apply to the testing of theories in general. Having noted this discrepancy, let us simply state that both *naïve* inductivism and falsificationism are prevalent and characteristic of school science.

Hodson (1985, p. 47) has argued for an "epistemologically more valid science curriculum,” since teachers’ inadequate understanding of the philosophy of science “leads them to project an unfavourable image of science and the activities of scientists through the hidden science curriculum.” The problem of “scientific method” only brings
to the surface in an obvious visible way the epistemological pitfalls of a science
curriculum which leaves many other aspects and attitudes concerning science “hidden”,
as Hodson and several writers have drawn attention to—what can be called the implicit
philosophy of the science curriculum. Several authors have termed this scientism. Bauer
(1992, p.144) refers to the assumption of epistemic privilege, the view that “science and
only science is capable of generating true knowledge, and moreover that science can
generate any true knowledge we may wish to have. Of course, the supposed secret of
science’s success was the scientific method.” He stresses “science is not scientism.” The
philosopher Susan Haack (2003, pp.17-18) describes the term as meaning “an
exaggerated kind of deference towards science, an excessive readiness to accept as
authoritative any claim made by the sciences, and to dismiss every kind of criticism of
science or its practitioners as an anti-scientific prejudice.” Writing earlier, Nadeau and
Désautels (1984) would have agreed with her general statement and Bauer’s point, and
see it consisting in two things:

Scientism is thus, in our view, both the attribution to scientific activity of an
exclusive claim to legitimacy and the active belief that science itself justifies its
particular status, because a valid answer to any question pertaining to it can only
be found through the application of its comprehensive method (pp.13-14).
Scientism clearly runs counter to the genuine legitimacy and value of science
(p.15).

Congruent with this exclusivist epistemic and methodological claim (usually
understood in strictly empirical terms) which is clearly a distortion, Duschl (1988, p. 51)
in describing scientism adds the inherent pedagogical authoritarianism: “a view in which
scientific knowledge is presented as absolute truth and as a final form,” along with the
lingering legacy of classical empiricism and logical positivism as the cloaked
epistemology behind curricula. The physics education researchers Roth and
Roychoudhury (1994), alternatively, identify (and derisively label) the hidden classroom
and student epistemologies as “objectivism.”

Nadeau and Désautels insist the “epistemological factor” must be incorporated in
science teaching to counter such myth-making in science classes. “In our view, the next
step must be to ensure that science teaching at the high school level is based on the
objective of instilling in the students a critical approach to scientific activity, as opposed to scientific mythology” (p.15; original italics). Their monograph although dated still presents several relevant insights and useful pedagogical devices to counter such myth-making (itemized below). (One notes their advice given over 25 years ago to consider the ‘epistemological factor’ has not been heeded). The Canadian science educator Glen Aikenhead (2002), writing recently and with explicit reference to their monograph, calls scientism an “ideology” embedded within science curriculum which acts as a kind of Trojan horse “by concealing its values when teachers attempt to enculturate students into Western science” (p.151).134

The dangers inherent to scientism as existing in both Western culture and the Western school science curriculum should not be denied or minimized; this can be better illustrated by looking at two cases germane to my thesis of the need of developing a philosophy of science education, the first with respect to the world of academia, the second with respect to science in the modern world. Gadamer’s own philosophical hermeneutic project in Truth and Method (1960/89) can be understood as a sustained argument against precisely this ideology with its presumed inductivist methodology and “epistemology of objectivism” forcing itself illegitimately upon the Humanities.135

Gadamer in fact takes explicit issue with the claim of epistemic privilege. In glancing at the contemporary relationship between science and society, several science educators (following the criticisms of sociologists of science—now referred to as “science studies”, being a recent research branch in science education) when recognizing the institutional and industrialized transformation of modern science into “techno-science” (Sula, 2009; Lacey, 2008), have warned against the naïve notion of a value-free and autonomous

134 Aikenhead has devoted his efforts to analyzing how school science education as part of a Western enculturation process when embodying scientistic epistemology can alienate students, especially First Nation youth who may not share the same values, “ways of knowing” and seeing the world (1997a). He has offered an unusual and constructive perspective for science educators, to consider their task and the curriculum as mediating a “cultural border crossing” for their students, between the worlds of academic science and their own home cultures (1998). This dovetails with my own views in so far as I would stress the language component as a key feature of the cultural disconnect for students (stated in chapter 5). My view does not dovetail in so far as Aikenhead tends to emphasize cultural relativism.

135 See his “Introduction”, also the “Foreword to the Second Edition”. Bernstein (1983, p.180) writes: “His entire philosophic project can be characterized as an apologia for humanistic learning. Gadamer, throughout his long career, has sought to show that the humanistic tradition, properly understood, is an essential corrective to the scientism and obsession with instrumental technical thinking that is dominant today.”
asocial science as perpetuated in schools due to the continued neglect of teaching the other dimension of current science as a techno-social practice. Lacey even argues the "commercialization of knowledge for profit" has brought about a new ethos for science, one he calls the "commercial-scientific ethos" (p. 311).

The commercialization and industrialization of science and its integration with contemporary technology are also important for the values of science itself. The central point here is not that all those engaged in what may be termed industrialized science are concerned directly with making saleable or otherwise useful products. It is that the industrialization of science, which has gathered such pace since the Second World War, has led to a set of social relations, priorities and values that represent a new kind of scientific activity whose malignant features are not always readily distinguished from the beneficial and benign (Jenkins, 1992, pp. 231-2).

The society sourced "scientism" so characteristic of technoscience, that some champion while others deride, is of a different sort than the classroom sourced kind often impugned by science educators, since it consists in taking no notice of the first sort—an irony. (Although both lack self-awareness, the ability to critically reflect on their own epistemological grounding). Seen in this light alone, textbooks when serving as the primary source of content knowledge (CK) must yield a one-sided and artificial representation of the modern scientific enterprise, contributing another feature to scientism, a kind of blind idealism:

... school science education must surely be more sensitive than it sometimes seems to be to the industrialization of science and all that this implies for its traditional portrayal of science as the disinterested pursuit of objective truth. The scientists of school science texts, Mendeleev, Joule, Scheele, Rutherford, Maxwell, Newton and Darwin, are not just deservedly famous individuals. They represent a kind of science that has little correspondence with most of the scientific research undertaken at the end of the 20th century (ibid, p. 232).

While I take note of the wider cultural implication of this ideological worldview what I find too frequently lacking among insightful critics, especially Aikenhead and his talk of the "Trojan horse curriculum", is the acknowledgement of the need to be just as mindful of avoiding the inculcation of beliefs and attitudes of the opposite extreme, either one of anti-science or one of indifferent epistemological relativism—that all cultural
knowledge claims are on par (metaphysical, religious, legendary, metanarrative, populist, or what have you), science being merely one among many and possibly not even exemplary at that (Loving, 1997). In our age we suffer from dangers at both ends, where the term “scientific” holds the dubious double connotation of being honorific as well as pejorative, depending upon one’s prior views and allegiance to the camps of modernist or post-modernist thought and critique, which surfaced in the late-1990s in academia and the press because of the Sokal hoax and “science wars” (Gross et al., 1996). Considering scientism we find that “‘Scientific’ has become an all-purpose term of epistemic praise, meaning ‘strong, reliable, good.’ No wonder, then, that psychologists and sociologists and economists are sometimes so zealous in insisting on their right to the title” (Haack, 2003, p.18). At the other end, “science is largely or wholly a matter of interests, social negotiation, or of myth-making, the production of inscriptions or narratives; not only does it have no peculiar epistemic authority and no uniquely rational method, but it is really, like all purported “inquiry”, just politics” (ibid, p.21). Haack wisely points out that a defense of science must carefully navigate the opposing shoals of scientism and anti-science, also typified by what she calls the stand-off between the “old Deferentialists” (especially the older logical-positivist school, but also Popper and Lakatos) and the “new Cynics” (Quine, Feyerabend, radical sociologists and feminists, rhetoricians, semiologists and philosophers outside philosophy-of-science). A useful philosophy of science education, I would argue, would need to judiciously proceed in a similar vein with its presentation of science for educational purposes, but this cannot be taken up here (Ogborn, 1995; Kelly et al., 1993).

I must take leave of the discussion involving modern science as techno-science with its implications (where STS reformers have been somewhat more cognizant and argued for curriculum inclusion of socio-technological impact issues), as well as the anti-science quarrel, to concentrate instead on better illustrating scientism in the curriculum and the theme of nature-of-science (NoS) more directly. Nadeau and Désautels associate five myths with scientism as manifested in school science curricula and classrooms:

1) Blissful empiricism (knowledge derives directly from observations)
2) Credulous experimentalism (experimental “proof” determines truth)
3) Naïve realism (scientific knowledge as a direct reflection of reality)
4) Excessive rationalism (only science brings us closer to truth)
5) Blind idealism (scientists as isolated explorers, disinterested, objective)

These same five can also be identified among McComas' (1998) catalogue of 15 myths attributed to school science, which teachers need to be made aware of and which should be addressed in classrooms.\textsuperscript{136} Evidence to support the claim of the popularity of these myths of scientism among students (learner epistemologies) was accumulated in a national sample study of Canadian students by Aikenhead and Ryan (1992). Using their own newly devised “Views of Science-Technology-Society” (VOSTS) test-instrument of 114 items, they surveyed the responses of over 2000 grade 11 and 12 students (urban and rural) to determine their NoS preconceptions and compared these to the five Nadeau-Désautels descriptors listed.

They generally discovered broad agreement with the scientism claim: 22% held to blissful empiricism (theories are discovered from facts), while another 40% held to a mixture of inductive discovery \textit{and} creative invention of theory (only 4% held that theories are creative inventions of mind); 22% held to “one method”, while 31% believed “evidence proves a theory true”, both indicators of credulous experimentalism. Another 42% held to “one method view” but also allowed for creativity of scientists; 19% held to naïve realism when asked about models in science (37% held they were “close to being copies of reality”). Only with “classification schemes” did 81% of students allow for human inventive character; 64% held to the simplistic and erroneous view that hypotheses become theories that become laws (McComas myth #1), which can be linked with excessive rationalism. Thereto, 36% held to a view that science progresses by disproving previous theories (akin to Popper), while 31% held to knowledge change and growth by reinterpretation (a view more akin to Kuhn, according to the authors). Finally, for blind idealism, 52% held that scientists are mainly unbiased and objective, and 47% rejected the idea of consensus-making when deciding whether to accept a theory (both

\textsuperscript{136} The first corresponds to \textit{myth} #5: “evidence accumulated carefully will result in sure knowledge” (p.58); the second to \textit{myth} #4: “a general and universal scientific method exists” (p.57) and \textit{myth} #6: “science and its methods provide absolute proof” (pp. 59-60); the third somewhat to \textit{myth} #13: “science models represent reality” (pp.66-67), although this is not strictly true. Whereas McComas fronts the idea of models here, Nadeau-Désautels take models primarily as instrumental and see in their use a strategy to overcome naïve realism; the fourth approximately to \textit{myth} #2: “scientific laws and other such ideas are absolute” (pp.55-6); the last to \textit{myth} #9: “scientists are particularly objective” (pp.62-4) and \textit{myth} #15: “science is a solitary pursuit” (p.68).
non-Kuhnian views). The authors also found that students confound science and technology, a myth identified by McComas (myth#14) but not by Nadeau-Désautels. They write: "chances are great that when students talk about science, they are probably talking about technology, specifically medical and environmental investigations" (p.564).

Several recent studies continue to reinforce many of these findings and the claim of scientism as manifested in school science (Lederman, 2007; Lederman and Abd-El-Khalick, 1998). The intensive cross-grade study by Driver et al. (1995) of English students (9, 12 and 16 years) also yields considerable evidence of the Nadeau-Désautels thesis, and several of the McComas myths. Ryan and Aikenhead conclude: "student naivete concerning the epistemology of scientific knowledge could seriously undermine the current attempts to increase scientific literacy" (p.572), concurring with Gallagher's previous view (1991, p.132) that the portrayed image of science for students is "both inaccurate and inappropriate." Driver et al., have pointed to studies that reveal how kinds of teacher epistemologies influence students' understanding of NoS, and depending on how language is used, students can be helped or hindered to develop more sophisticated understanding (see Merzyn, 1987). (The role of language will be addressed in Ch.5).

Although teachers tend to be "eclectic" in their perspectives "they have not had opportunities themselves to reflect on and clarify their own views on the subject." Rather "the dominant picture of science lessons" which emerges "is of teachers tending to represent science as a body of facts together with a set of mechanical empirical processes" (p.149). Their own observed research experiences in classrooms "suggest that current teaching practices are portraying a limited perspective" of NoS, while the English National Curriculum presents "a restricted epistemological perspective" (p.143).
4.6. Epistemology and Philosophy of Science: Objectivism and Representation

When re-examining the Nadeau-Désautels’ myths of scientism, several of these can be linked with well-known views in the older pre-Kuhnian philosophy of science. Thus, "blissful empiricism" corresponds to classical inductivism, and both this myth and the next "creduulous experimentalism" taken as verificationism indicate parallels with classical logical positivism. It is not altogether surprising then, that when science educators wish to denounce school science epistemology they often refer to it derisively as "positivism", which has become a catch-all phrase (see Roth and Désautels, 2002; Burbules and Linn, 1991). Aikenhead and Ryan (1992, p.561) are typical and their view gives insight into their interpretation of their survey instrument: "Student views that converge with Barnes, Holton, Kuhn, Snow, or Ziman are considered to represent a worldly perspective. Views that diverge from this contemporary literature are thought to be naïve. Naïve views are often identified with logical positivism." Unfortunately such labels are misleading and inaccurate and science educators need to be more circumspect. Scerri (2003) serves the same warning to chemistry educators. "Naïve realism" cannot be assigned to positivism, for it was anti-realist and instrumentalist when it came to theories and entities. (Such aspects of positivism, including its strong anti-metaphysics bent, can in fact be more aligned to epistemological relativism of current postmodernist thought, which assumes anti-realism and takes truth and knowledge to be relative to a socio-conceptual frame).

What I find more disturbing is that too often science education critics do not distinguish naïve from critical realism—a viable and eminent school of thought in current PoS. (Here the nature and status of scientific models, theories and entities are debated and of great importance). Moreover, if "creduulous experimentalism" is taken as instances of Popperian falsification it must exclude positivism. Indeed, this myth, adding to it "excessive rationalism" and "blind idealism" together show some surprising similarities to Popper's PoS. One could no doubt also find some affinities with simplified versions of Lakatos' views concerning myths #2, #3 and #4. Hence, it would be more accurate if science educators associated scientism more closely with several positions of the "old Deferentialists" (Haack) or what has been termed "the received view" of science (Suppe,
1977). Ladyman (2002, p.95) lists seven attributes that Popper, the logical positivists and logical empiricists shared:

1) science is cumulative: progress of science is a steady growth in knowledge
2) science is unified: there is a single method; sciences are reducible to physics
3) logic of confirmation or falsification; such evaluations are value-free
4) sharp distinction between observational and theoretical terms; observation and experiment provide a neutral language for the testing of theories
5) scientific terms (language) have a precise and fixed meaning
6) epistemological distinction between the context of discovery and justification
7) sharp demarcation exists between scientific and other belief systems

Clearly most myths of scientism, especially if one includes those of McComas, can be associated with one or the other of these stated attributes. More importantly, the coherence of these attributes and attitudes can function as a single “scientistic” worldview. What is also obvious is that Kuhn’s and Feyerabend’s philosophy of science rejects all of them (including critical realism), and in so far as the science curriculum assumes or implies or outright accepts one or several of these theses it can be rightly accused of harboring an out-dated and discarded PoS. Modern PoS has truly entered a post-Kuhnian phase (and there can be no doubt he symbolizes the breaking point; Nola and Sankey, 2000), albeit it remains divided and disturbed regarding the worth of his central theses. I submit a better case can be made designating the epistemology of school science as well as that of the “received view” in PoS, which underlies scientism, as objectivism.\(^\text{137}\) By this is meant the epistemological standpoint with its tenets at the core of Enlightenment philosophy as it developed in tandem with the advancement of science since Galileo and Descartes in the 17th century.

The idea of a basic dichotomy between the subjective and the objective; the conception of knowledge as being a correct representation of what is objective; the conviction that human reason can completely free itself of bias, prejudice, and tradition; the ideal of a universal method by which we can first secure firm

\(^{137}\) Not to be confused with the scientific attitude to strive to be objective in argument and research.
foundations of knowledge and then build the edifice of a universal science; the
belief that by the power of self-reflection we can transcend our historical context
and horizon and know things as they really are in themselves (Bernstein, 1983,
p.36).\textsuperscript{138}

Certainly modern philosophy since Descartes has wrestled enormously with the
question of "how to know the real?" and delineating "what is real?" (ontological problem
of metaphysical realism), and it is well-known the Kantian tradition had prohibited
knowledge about the "thing-in-itself" and severely curtailed the ambitions of empiricism.
(Rockmore notes that Kant represents a shift from ontological to epistemological realism,
often unacknowledged in the Anglo-analytic tradition; 2004, p.17.) Still, modern
epistemology as a theory of knowledge was essentially a theory of representation (Rorty,
1979), and various schools of thought sought to enunciate how knowledge could best be
grounded, what kind of representation would be appropriate and how it could be secured.
Both rationalism and empiricism (playing out the ancient tension between intuition and
observation) were greatly influenced by the developments of modern science to look for
answers to metaphysical realism and the epistemological quest. The rationalist tradition
(e.g. Descartes, Leibniz) not surprisingly saw in mathematics and mechanical physics a
model for attaining sure knowledge (hence the primacy of "reason" and the \textit{a priori}
access to truth), while empiricism (e.g. Locke), and much later, logical positivism-
empiricism (also Russell and the early Wittgenstein) remained very skeptical of
theoretical constructs and looked to the senses, observation, induction and the
experimental sciences and their method as a better foundation (primacy of sensory
experience and the \textit{a posteriori}). With the collapse of foundationalism generally—as
adopts important defenders are found today—representational realism as common to both
traditions has suffered credibility along with the \textit{correspondence theory of truth}.

A paradox is revealed by the fact that the evolution of science—itself a curious
synthesis of rationalist and empiricist ideas and attitudes (no doubt contributing to its

\textsuperscript{138} He provides another description "... the basic conviction that there is or must be some permanent,
ahistorical matrix or framework to which we can ultimately appeal in determining the nature of rationality,
knowledge, truth, reality, goodness, or rightness. ... Objectivism is closely related to foundationalism and
the search for an Archimedean point. The objectivist maintains that unless we can ground philosophy,
knowledge, or language in a rigorous manner we cannot avoid radical skepticism" (p.8).
immense success)—which helped shape debates in philosophy (still occurring today in philosophy of science) has itself remained relatively immune to developments in philosophy in the past 300 years, above all the quarrels in epistemology over foundationalism and the status of knowledge:

It is at least interesting that foundationalism is not accorded attention in cognitive disciplines other than philosophy. For instance, it plays no visible role in modern science, where everything happens as if foundationalism were an irrelevant consideration. Neither Galileo nor Newton nor Einstein nor indeed any reputable scientist in modern times has ever tried, or even voiced the concern, to put science on a foundationalist epistemological basis. Yet philosophers deeply acquainted with science, such as Descartes, Kant, and Carnap, have made this effort, as if science without an epistemological foundation was somehow incomplete (Rockmore, 2004, pp. 45-6).

This is not to say scientists have been entirely unconcerned about epistemological issues and the nature of knowledge, and indeed as the disagreements over realism and instrumentalism in the long history of science clearly show us (to be discussed in next Section). Scientists have quarreled not only with philosophers and theologians but also among themselves, particularly for those individuals wearing the dual philosopher-scientist hat (e.g. Galileo, Descartes, Leibniz, Priestley, Mach, Helmholtz, Eddington, Bohr, Heisenberg, Eger, Gould, and others). Although it may be true to assert as Rockmore does that science has been in the main oblivious to the foundationalist project as taken up primarily by philosophers, it has not been unmindful when it came to ascertaining the status of scientific knowledge, and here science and philosophy exhibit a rich and reciprocal history, well-described by Cushing (1998) and Westfall (1971). And the tenets of objectivism can be recognized as the common and often hidden background to most philosophizing.

The ethos of modern science, unlike epistemological foundationalism, is purposely fallibilist (the other exception being pragmatism)—hence subject to correction on empirical grounds—yet this fact has not stopped “the modern debate on knowledge, perhaps even the analytic debate throughout the 20th century, [to] mainly consist of a series of variations on Platonic themes” (Rockmore, 2004, p.29). In a similar vein Ogborn (1995, p.19) refers to this line of thought as the “rationalist programme” and
“rationalist ideology”. There seems little doubt that a Platonic notion of knowledge as “direct access to things” (and as Rockmore notes, quite often ignoring the Kantian epistemological revolution) inhabits both Enlightenment and scientific philosophy—although falsely projected onto science—including science content knowledge (CK): the claim to attain immutable and certain knowledge, those facts, entities and laws assumed not subject to change and historically contingent, and that somehow when it comes to truth—especially about the natural world—science manages to ultimately “get things right”. Such a position can be voiced in stronger and weaker forms, and most philosophers of science (inclusive of positivists as unrepentant empiricists, though restricted by them to the observation language) including Popper would argue that science “tracks truth” in some way, the weaker form only admitting that scientific theories “approximate truth”. Such a position in whatever version is called convergent realism. One immediately identifies several myths of scientism discussed earlier here, namely “excessive rationalism” and “naïve realism”, although depending upon how the argument is framed and the issues understood, there need not necessarily be anything excessive or naïve about such views; the myths could signify degenerate and overly simplified views of legitimate objectivist positions. The Nobel Prize physicist Weinberg (1992) asserts that unless science is getting closer to truths about nature, it must remain condemned as an irrational activity.

There has always been the concern as to how certain scientific knowledge could be: “Are the laws and theories of science nothing more than one contingent way to describe the world, or do they yield truth?” (Cushing, 1998, p.12). The school curriculum I assert, exhibits an unconscious and unbroken allegiance to Platonic realism underlying its presumed objectivist notion of knowledge, taking it matter-of-fact to be ahistorical and beyond significant change, and hence why epistemic content (CK) can be laid out the way it traditionally is in science textbooks of all kinds: technical scientific knowledge (be it Snell’s law of refraction, motion, chemical bonding, cell theory or cellular respiration, etc) is assumed to “stand above things” and therefore can be abstracted out of the historical matrix, structured without context and “known” without any hint of its developmental history—the historical context being thought irrelevant. One can call this the fallacy of Platonic realism which justifies epistemic content knowledge.
Duschl et al. (1990) correctly emphasize that content knowledge (CK) and any related discussion of a particular theory of science (e.g. plate tectonic theory) is usually taught from the ahistorical context of justification mode (without regard to predecessor theories) instead of the historical context of discovery mode (which includes alternative predecessor theories). Such an instructional staging, taking a Kuhnian view, is thus made strictly within the bounds of paradigmatic normal science, which is quite common and how most material is presented. I would add that this staging assumes knowledge objectivism. Not only is such an instruction “epistemologically flat” it is usually accompanied by historical versions that are highly over-simplified and often outright inaccurate (Allchin, 2003).

If objectivism as a worldview inherent to both philosophical foundationalism and scientism is to be abandoned, what other viable alternatives now present themselves, other than skepticism and relativism? What better conceptions of what “knowledge” is, and entails, can be found (Mason, 2003)? There are some thinkers who now argue our very idea of epistemology must be forsaken while the time-worn notions of “reason” and “knowledge” are to be radically reconceptualized. Some in science education have seen an alternative in philosophical constructivism, but this move is highly contested (Matthews, 1998a). Others have suggested this could mean a turn “from epistemology to hermeneutics” as Rorty (1979) and Gadamer (1960/89) have argued—this anticipates my last Chapter. There remain other philosophical and literary traditions that can be looked to and drawn upon.139

139 See for example von Glasersfeld (1989, p.124): “The word ‘knowledge’ refers to a commodity that is radically different from the objective representation of an observer-independent world which the mainstream Western philosophical tradition has been looking for. Instead ‘knowledge’ refers to conceptual structures that epistemic agents, given the range of their present existence within their tradition of thought and language, consider viable.” It is curious that both von Glasersfeld and the later Kuhn (Bird, 2002) developed Kantian constructivist positions, yet Kant is very much in keeping with Western objectivism. 140 “One is the emergence of a weaker, anthropological, culturally based, historically relative views of knowledge in Wilhelm von Humboldt, Herder, Fichte, Hegel, Marx, Dilthey, Gadamer, and other writers. The other is the rise of classical American pragmatism. Pierce, and those influenced by him, including James and Dewey, share his anti-Cartesian concern to formulate a nonfoundationalist view of knowledge which, with the possible exception of James in his radical empiricist phase, gives up familiar claims to know the mind-independent real as it is” (Rockmore, 2004, p.27).

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The modern version of Platonic realism is widely represented in the writings of modern philosophers and working scientists committed to a grasp of the mind-independent external world. Long after Kant, Platonic realism survives in our time in the persistent, stubborn, dogmatic, indemonstrable but widespread commitment by philosophers, philosophers of science, and scientists alike, distantly following the Cartesian form of metaphysical realism, to claims to know the mind-independent external world as it is in all its many forms (Rockmore, 2004, p.32).

Having assumed to have correctly grasped the “external world” as behooves objectivist prejudice—to whatever degree, especially assuming the objects of representational realism are largely suitably mirrored—then the play of scientific words, definitions, symbols, equations and processes as constitutive of the bulk of curriculum can be learned for themselves in a decontextualized fashion and socio-cultural and historical vacuum. Though textbooks and reform Standards documents certainly often parrot the “tentativeness of scientific knowledge” yet this seems mere lip-service compared to how textbook epistemic knowledge and classroom learning are structured.

Moreover, the reader has hopefully recognized that certain other tenets of objectivism as quoted above have clearly found a home in the science curriculum: the “subject-object dichotomy” that lies behind the transmission language model of instruction and conceptions of learning (including typical subjectivist-based cognitive learning models); the “ideal of universal method”; the notion of a “unified universal science” (ultimately reducible to physics) witnessed to by the very conception of the name of our discipline, “science” education; lastly, the belief of being able to “transcend the historical context”—the last point refuted by Gadamerian philosophical hermeneutics.

We come now to another key tenet of objectivism quoted above, the crucial topic of the “correct representation of what is objective”, that is, the representational nature of scientific laws, models and theories. The assumption that our constructs “represent well” is taken for granted in all science courses—the historicity of these items masked by both the language employed and the logic of disciplinary structured edifice (Sutton, 1996; Kuhn, 1970)—overlooks the fact these representations (theoretical constructs) have frequently undergone a transformative process (in symbol, concept and meaning) during development and revision in scientific communities (e.g. gene, atom, electron, planet,
element, mass, law of freefall, Ohm's law, and many, many others) and some remain objects of much contention in current philosophy of science (realism/instrumentalism debate). In the physical sciences they have become increasing abstract and removed from the everyday world of both the layman and the learner. Some have even been led to conclude that Representationalism has been abandoned in science itself:

Representation is always representation of something else. The Cartesian view of the scientific object banishes sensation in favor of geometrical schematism, which also holds in Newtonian mechanics. It later gives way to field theory, in which (when things are replaced by an aggregate of physical relations) representation takes the form of a purely symbolic relation. In the latter case, complex mathematical relations refer to or symbolize, but no longer represent, an aggregate of properties as distinguished from things. In the standard, or Copenhagen, interpretation of quantum mechanics, the so-called measurement problem suggests that the very idea of an independent object must be abandoned. Yet at a time when epistemological representationalism has lost its importance in science, it still remains central in philosophy (Rockmore, 2004, p.90).

The conclusion seems highly premature. Quantum mechanical (QM) field theory has surely pushed the limits of traditional representation but its epistemological interpretation with respect to realism remains very contentious, to say the least (Cushing, 1998). Yet the irony should not have escaped Rockmore that while QM appears to put into serious doubt several of the aforementioned tenets of objectivism the physicist Weinberg, whom he correctly chides, still holds proudly to his naïve realism. Nor should problems in micro-physics be taken to stand for the situation of the sciences in toto.

Without question, laws, models and theories as sophisticated and highly explanatory representational (and idealization) modes of reasoning remain the pride of science and the hallmark of its success, and hence representationalism in its many forms needs to be treated with the utmost respect in science education, even so, if one just wishes to accept them as heuristic devices (as tools) and leave the contentious realism aspect and question to the side. To dismiss them simply as "naïve realism" (as too many critics, including Aikenhead and Roth are wont to do) is to do a disservice to both science and science education, where the latter, unfortunately, too often fails in properly accounting for the value and differences of laws, models and theories for learners (Hodson, 1991). I will now briefly articulate this.
For my part, I take it as self-evident that to build a scientific mind requires in large part the ability to explain phenomena and justify one’s explanations. This is exactly where modeling and understanding the role of theories must come to the fore. Both explanation and argumentation are taken to be at the epistemic core of scientific reasoning and the research on the value of understanding theory change and modeling in learning science (Matthews, 2007; Gilbert and Boulter, 2000) complements the work of those who suggest it directly reinforces critical thinking, that is, the quality of logical reasoning and argumentation discourse in the science classroom (Osborne et al., 2004; Giere, 1991), as well as better illustrating the character of historical conceptual revolutions (Nersessian, 2003; 1989; Duschl, 1990).

An understanding of scientific explanation should encompass fundamentally four aspects: insight into the explanatory role of laws; thereto, secondly, insight into the conceptual structure and historical establishment of a theory (including the empirical laws it can deduce and the rational nature of theory change, Duschl, 1990); thirdly the kinds and functions of models it contains, and hence, finally, the nature of scientific reasoning. Scientific explanation in its widest sense is often taken to mean “theorizing” but this is commonly construed as primarily inferring hypotheses, creatively constructing models and assessing (testing) their individual predictions (Giere, 1991 and Figure 2). Though this partial picture is true and certainly helpful, it overlooks the place of prior theory and the theory-ladenness of data collected in the inquiry process. A theory in itself is a complex conceptual creation which is (usually) comprised of a set of models, each restricted to specific domains intending to capture and abstract a given aspect of reality (ex. Newtonian classical mechanics employs various particle models—free particle in uniform motion in the limit of low-velocities;
A flow chart corresponding to the program for analyzing reports of scientific episodes involving theoretical hypotheses.

**Step 1**
REAL WORLD

Model fits / Doesn't fit
Hypothesis True / False

**Step 2**
MODEL

**Step 3**
Observation / Experimentation

**Step 4**
Reasoning / Calculation

**Step 5**
Data and prediction agree?

**Step 6**
Was the prediction likely to agree with the data even if the model does not fit the real world?

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The data are inconclusive regarding the fit between the model and the real world.
uniformly circulating particle subject to a net centripetal force, etc. Halloun, 1996).\textsuperscript{141} As a rule theories cannot be tested directly, only indirectly through the use or application of their models. From an epistemological perspective models are said to mediate between theories and reality. On this view models are subordinate to theories, but what they lack in broader explanatory power they make up for in their ability to present immediate testable consequences. (In the normal course of teaching the subject matter of a given theory, instructors should explicate these differences.) Students then, must also come to recognize these four aspects of explanation. They can be provided with opportunities to explore theories and laws, and in appropriate laboratory and field settings can confirm established laws and models, occasionally even test their own hypotheses and models.\textsuperscript{142} Theories though, usually remain very much outside any such classroom possibility.

On the other hand, one way assessment of theories can be undertaken is by using an historical approach, by choosing studies of those examples in the past where rival high level theories have confronted each other. In those rare cases where theories clash (e.g. Ptolemaic or Keplerian astronomy; Newtonian or Einsteinian physics; phlogiston or Lavoisier’s chemistry; young-earth theories or evolutionary geology, etc.), the particular limits and defects of their respective models become sharp. Such instances can serve as an effective teaching strategy to help students discover how knowledge can progress, and thus illuminate for them the precarious nature of how science actually advances. Such ideas present a viable alternative to the reigning scientism of the curriculum, and helps illustrate the distinction between (and proper roles of) laws, theories and models.

Duschl (1990) argues that because theories are the primary explanatory engines in science a study of their history, structure, evaluation and change should serve as the guiding cognitive framework for the disjointed and over-crowded information-based epistemic content arranged solely around subject topics (e.g. light, heat, motion, bonding, reactions, body systems, etc). “It is a common mistake of laypeople [and the media] to

\textsuperscript{141} “A theory may be thought of as a family of models. Different models are derived from a theory using different idealizations, different simplifying assumptions, and different auxiliary hypotheses. Many different models can be derived from a single theory. For instance, if we assume that there are six planets, which are small point masses, then we get one Newtonian model of the solar system. But if we assume that there are 7 planets, or if we model the Earth as bulging at equator, then we get different Newtonian models of the solar system” (Forster, 2000, p.236).

\textsuperscript{142} With the growth of computer based simulations in classrooms today, students now have the opportunity to run modeling scenarios for some subject topics, especially in physics and chemistry.
equate scientific theory with scientific fact” (p.7). He asserts that unless students begin to understand how theories are rationally debated, displaced and confirmed by the scientific community they will fail to see science either as a rational enterprise or respect the nature of scientific knowledge. (Sometimes these disputes can take decades: Copernican theory took about 150 years; Plate tectonics about 60, and QM about 25 years). Based on HPS research “an understanding of the growth of scientific knowledge is best obtained through an understanding of the development of scientific theories” (pp.7-8). Drawing substantially on several thinkers like Lakatos and Laudan, and avoiding many of Kuhn’s theses, he draws up six epistemological models to characterized knowledge growth and theory change in science (goals-of-science hierarchy; levels of theories; argument pattern for testing theories; four criteria for evaluation; triadic network; tripartite process). Especially useful are his four criteria (logical, empirical, historical and sociological) whereby theories can be judged, and distinguishing between core, frontier and fringe theories. Furthermore, he has provided several helpful examples for teachers of how epistemological frameworks can be applied to actual historical case studies (theory of periodicity of elements; motion theory; plate tectonic theory).

Duschl’s presentation is not of the usual cumulative sort, and students can discover the revolutionary nature of theory change without failing to grasp the overall rational nature of scientific reasoning, of argumentative discourse and deliberation. His is the most elaborate and useful epistemological-based science education yet developed. (It is useful because it explicates an authentic epistemology of science that teachers can incorporate, however, because it is strictly epistemological it suffers the failing of ignoring educational metatheory.) It can be taken to directly challenge and overcome scientism, especially those tenets of objectivism that present content knowledge (CK) predominately as static, highly durable and final, as ahistorical and thematically isolated. One epistemological drawback is his failure to properly account for the nature and relation of models with the theories he discusses.

In the analysis of the function of theories and models in science as useful for science education one needs therefore, once again, to discriminate between the common “knowledge-justification” framework and the neglected “knowledge-development” framework, and reinforce the latter. (This distinction is often compared, though in a
rather crude and inaccurate manner, to Kuhn's two aforementioned distinctive science stages, "normal" and "revolutionary". Regrettably, this is usually not done, not even by those stressing modeling for science education, where the exciting revolutionary shifts of theories get short shrift or is simply ignored. While Kuhn does us a great service in clarifying the crucial role of modeling in "normal science"—this is not clarified in science education generally (for instance, models for "light rays" or the "Bohr atom" are taken as historically static and as direct visual representations of reality)—he unfortunately says little about its worth for theory change and revolutions.

On the other hand, the philosopher of science Malcolm Forster (2000), distinguishes between three levels of theorizing which form a hierarchy: at the top are fully developed (and paradigmatic) theories which govern a science; models form the middle tier, which allow for the concrete applications of the theory, and predictive hypotheses of the model at the lowest tier, that allow/disallow for fitting the model to the data (Figure 2). He also argues, when considering the contentious question of the ontology of theories, that there exists a "trade-off" of truth against predictive accuracy as one moves up the levels. Scientists tend to incline towards instrumentalism with their models but towards realism with their theories. They also tend to realism in stable periods of normal science, shift to instrumentalism during revolutions, and revert back to realism with the return to normal science.\textsuperscript{143} On Kuhn's view of science (which is helpful for educators), "normal science concerns the development of the middle layer—at the level of models. Revolutionary science involves a change of [core] theory at the top" (p. 232).

Conventional science education, I repeat, is preoccupied with disseminating the established theories of this stable stage of "normal science" while overlooking revolutionary theory change, but at least Kuhn openly reinforces the vital role of modeling there (see further paper by Schulz and Sivia, 2007). This brings us foursquare to the question of the epistemic status of theories.

\textsuperscript{143} The degree to which models can be interpreted to "approximate truth" in nature (i.e. their realist status) is debated in philosophy of science: Giere's "constructive realism" versus Van Fraassen's "constructive empiricism" (Giere, 2005).
4.7. PoSE Case Study: The Realism/Instrumentalism Controversy in Philosophy of Science and its Value for Science Pedagogy

The science education literature has earlier addressed aspects of the realism debate (Eflin et al., 1999; Slezak, 1994a,b; Matthews, 1994, Kelly et al., 1993; Hodson, 1991) especially with regard to criticisms of radical constructivists (e.g. Roth and Desautels, 2002; Von Glaserfeld, 1989) by writers like Matthews (2000), Nola (1997) and Loving (1997). Recently science educators have seen fit to defend realism again and published substantial reviews (Coburn and Loving, 2008; Ogborn, 1995). What surprises is that the position taken there openly espouses “commonsense realism” which Rockmore (2004) would criticize as a return to a version of “direct realism” (or “intuitionalism”) akin to, he argues, phenomenology and Greek thought, which is widely held as untenable today. I agree with this assessment and will not address this literature, nor concern myself with the constructivism controversy, but wish instead to seek to ascertain the degree to which critical realism can be defended by going directly to the realism/instrumentalism debate as discussed in philosophy of science.

Realism as a philosophical doctrine is not overtly discussed in science education curricula, however, and usually two extremes of naïve realism and instrumentalism can be identified, as mentioned (Hodson, 1991; Selley, 1989). Naïve realism tends to dominate and is displayed in two general ways: often explicitly (asserting genes, black holes or tectonic plates “exist”)—but not obviously (when texts misleadingly state “the electron was discovered by J.J. Thomson in 1897” ignoring the prehistory)—or implicitly when deliberately making the epistemic slide across the theoretical construct/observable divide, with models taken too literally, as cited previously. Instrumentalism occurs infrequently, depending on the nature of the subject matter, although it usually manifests itself when a strong version of empiricism (“positivism”) and thereto when measurements and data are overly stressed, models and theories taken as entirely fictive, and the status of theoretical entities are undervalued. Teachers and curricula could present it, for example, when discussing chemical bonding, fields, wave/particle duality, or the quasi-historical change of atomic models, including quantum mechanics (Elkana, 1970).

The realism/antirealism debate in POS is complex, taking different forms in different branches, and can appear convoluted to those of us entering the discourse from outside that discipline, though even philosophers of science have themselves admitted “these debates are often Byzantine and confusing” to those working in the field (Eflin et al., 1999, p.114). It will be granted that the science educator has all the more reason to proceed with caution, especially since it can be acknowledged that students “on first exposure misunderstand antirealism and instrumentalism”, but that does not warrant the
claim that therefore “debates about realism should be avoided, and that a naively realist view is most appropriate for science education” (ibid.). Such a suggestion is energetically rejected for at least three reasons: the inherent naïve realism and inductivism in the curriculum and the misunderstandings with respect to NoS that necessarily follow must be countered; this is based on the argument, secondly, that the debate is integral to how science has developed and its value been interpreted (mirrored by the “intelligent design” versus evolution dispute; Brockman, 2006), and thus its neglect would seriously impede proper comprehension; lastly, within the science education research community certain detrimental antirealist views have become ingrained and need to be challenged. Currently weaker and stronger forms of realism have been expressed, but it is my view (along with others) that a modest or critical realist version can be articulated for science education that, on the one hand, attempts to do some justice to the intricate debates within POS and yet, on the other, can be presented in an appropriate form to teachers and students.

Matthews (1994, p.177) has stated four general theses of such a position. He claims further that “[i]t is enough to go with, and it is incompatible with empiricism, with constructivism and particularly with idealist forms of radical constructivism.” One can take issue with his view it must be incompatible with constructivism per se, and his claim that the arguments against “verisimilitude” have been countered (see below). His four theses are: i) theoretical terms in a science attempt to refer to reality (uncontested by realist and antirealists alike); ii) scientific theories are confirmable (note he correctly avoids the use of problematic terms like “verified” or “falsified”); iii) scientific progress, in at least mature sciences, is due to their being increasingly true (the doctrine of “approximate truth” or verisimilitude, which is strongly contested); iv) the reality that science describes is largely independent of our thoughts and minds (also termed “metaphysical realism”, and also contested).

The realism/antirealism controversy is actually an old one in POS, going back to the logical positivists (instrumentalists) of the Vienna circle in the 1920s—what can be considered the beginning of the discipline itself—and earlier to French thinkers such as Duhem (instrumentalism)\(^{144}\), Comte (positivist-phenomenalist) and Poincaré

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\(^{144}\) One must be careful here about attributing positions to complex thinkers. Duhem did indeed hold the line against atomism and other theories positing theoretical entities at the turn of the 19th century (as many others did as well, including the famous chemist Ostwald, who only converted towards the end of his life). On the other hand, he presented at least three good arguments against the instrumental (anti-realist) view of theories as mere calculating devices (i: actual scientific practice and aims; ii: novel predictions; iii: the theoretician’s search for unity/unification to explain phenomena). And his adherence to science as a
(conventionalism), as well as German scientists of the late 19th century such as Planck (realist) or Kirchhoff and Hertz (phenomenalists). These latter held to the view that "the job of physics was to provide a complete, accurate and simple description of the phenomena of nature, rather than an understanding, either in terms of models or in terms of principles a priori necessary or self-evident to the human mind" (Cushing, 1998, p.367; italics added).

Moreover, the historical record of scientific development (HDS) equally exhibits this controversy, going as far back as the Copernican revolution (Kuhn, 1957/85). The Ptolemaic and Tychonic (earth-centered) theories, strongly held to be "real", nonetheless permitted the Copernican (sun-centered) theory as a useful computational (anti-realist) model for over a century ("empirical adequacy"). The subsequent theoretical successes of Kepler, Galileo, Newton and classical mechanics in general convinced many of the metaphysical and epistemic realism supposedly inherent to scientific theorizing and methodology for over 200 years. Yet at the turn of the 19th century the debate over atomism in physics and chemistry revived anti-realism (e.g. Planck versus Mach (Toulmin, 1970). The famous Russian Mendeleev, co-creator of the Periodic Table along with Mayer, opposed attempts (unlike today) to reduce the periodicity of elements to atomic structure and dismissed radioactivity and the electron's existence. Ostwald in Germany, the most well-known chemist (and textbook writer) of his time rejected atomism as late as 1905 (Scerri, 2007). Then just as the majority of scientists had reluctantlly come to accept the existence of atoms (and electrons) the controversy reared up again and was reshaped due to Einsteinian relativity (in 1905/16) and the conceptual and methodological revolution of modern quantum mechanics (QM) in the 1920s. It is well known that realist-inclined scientists like Einstein and Schrödinger (one of the founders of QM) strenuously opposed the instrumentalist (positivist) conception of QM as would become officially endorsed in the so-called "Copenhagen interpretation" by Bohr, Heisenberg and others (Cushing, 1998; Toulmin, 1970). The epistemic status of QM remains unresolved and continues to engender rigorous debate among scientists and philosophers alike.

Within the philosophy of science community itself the scientific realism debate although occasionally dismissed as sterile or even "dead" has experienced a remarkable

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145 Matthews (1994, ch.8) traces the conflict even further back, to Platonic "realism" and Aristotelean "empiricism". He presents other insightful historical examples of the recurring simultaneous clashes between the two opposed philosophies: Copernican/Ptolemaic realism and Osianer's empiricism; Newton's realism and Berkeley's empiricism; and Planck's realism and Mach's empiricism.
revival in the 1980s and 90s (Psillos, 2000; Boyd, 1983). This has been due to the abiding force of anti-realist arguments put forth by Quine, Kuhn and Feyerabend in particular (in the 1960s and 70s), lately reinforced by arguments of Bas van Fraassen (1980) and Larry Laudan (1981), and the concerted efforts by several authors, such as Boyd (1983), Devitt (1984), Aronson et al. (1995) and Psillos (1999), to challenge and rebut them.

The upshot of the preceding overview is to emphasize not only the longevity, vitality and unresolved nature of this controversy, but to equally help guard against those writers (philosophers, postmodernists, scientists, sociologists, feminists and sundry cultural critics), science educators and popular science writers who would dare declare the debate either dead or decided (in one direction or the other). Thus their attempt to claim the authority of authors like Quine, Kuhn, Feyerabend, Van Fraassen, etc., to help buttress their own anti-realist bias, or conversely, claim Boyd, Devitt, Psillos, the objectivist tradition and even the views of scientists themselves (biologist Wolpert, 1992; physicist Weinberg, 1992) as evidence to support their exaggerated claims for scientific realism. The former instance has certainly happened with some authors arguing for science education as social action (Roth and Desautels, 2002) or “culturally appropriate science” (Loving, 1997; Matthews, 1994) or for radical constructivism. One can concur with Matthews (1998a) that prematurely tipping our hat towards either camp, although tempting, would conflict with our role as educators.\footnote{This certainly is the case with Roth and Lucas (1997). In examining their research work they can quite fairly be accused of indoctrinating their students into an anti-realist/radical constructivist ideology.} This does not mean we must choose to remain agnostic or indifferent on this crucial subject. It does mean we must be, at minimum, cognizant of the arguments and historical clashes pertinent to the two opposing positions.

It should be clarified that most people are not anti-realists about “observables” (such as dinosaurs, planets, volcanoes, bacteria, cells, etc.), often referred to as “common sense realism” or “everyday realism”. Usually there is little dispute here, although some writers such as creationists try to question the accepted Darwinian theoretic explanations of certain observables, kinds and classes. (And there can be considerable debate about kinds as interpretive categories: e.g. ‘species’, ‘intelligence’, ‘memory’, ‘race’, ‘gender’, etc.). And of course there always exist the possibility, in fact it occurs quite frequently, of differences within disciplines when empirical data is scrutinized, be they among medical researchers, archeologists, cosmologists, paleontologists, anthropologists, or what have you. But these are not cases questioning scientific realism, which is commonly taken to mean belief in unobservables or theoretical entities and laws.
Because of Kuhn’s influence and popularity it is perhaps appropriate to restrict our examination for the sake of brevity to his claims concerning anti-realism. Kuhn aims to defend the thesis, quite contrary to what many people and most scientists hold, that science does not progress, or is not progressively objective—that modern theories do not present a truer picture about nature—across revolutionary divides (or “paradigm shifts”, when radical conceptual change occurs as theories are discarded and replaced), because historical research “gives ground for profound doubts about the cumulative process” (p.3). This has led to accusations that his analysis suffers from epistemological relativism (Siegel, 1987).

As a preliminary comment one must distinguish in Kuhn’s method his recourse to history from his philosophical interpretations of his historical case studies and examples. It is mainly the latter that have engendered considerable dispute, although the former has also come under scrutiny (Pyle, 2000; Brush, 2000).

Another point is that relativists can be “hoisted on their own petard” given that their methodology presupposes those very aspects of science that they question and seek to undermine. In his 1970 Postscript response to his critics (with an oft-quoted passage) Kuhn reinforced his earlier (1962) theses in Structure about NOS:

There is, I think, no theory-independent way to reconstruct phrases like ‘really there’; the notion of a match between the ontology of a theory and its “real” counterpart in nature now seems to me illusive in principle. Besides, as a historian, I am impressed with the implausibility of the view. I do not doubt, for example, that Newton’s mechanics improves on Aristotle’s and that Einstein’s improves on Newton’s as instruments for puzzle-solving. But I see in their succession no coherent direction of ontological development... Though the temptation to describe that position as relativistic is understandable, the description seems to me wrong. Conversely, if the position be relativism, I cannot see that the relativist loses anything needed to account for the nature and development of the sciences (pp. 206-7; my italics).  

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147 There is considerable overlap with certain Feyerabendian theses such as incommensurability. Arabatzis (2006) argues that Feyerabend unlike Kuhn developed the more sophisticated philosophical arguments and hence restricts his attention to him when it comes to analyzing meaning variance for example. Bird (2002) agrees with this general assessment of Kuhn and so explains his lack of overall relevance for philosophers. Yet notwithstanding these views Kuhn continues to exert considerable influence across disciplinary fields. And it appears that philosophers of science have rather too quickly written him off (Laudan, 1990). As Forster (2000) himself admits, to be anti-Kuhn is taken as being a card-carrying philosopher of science.

148 Laudan (1990) has explicated six significant theses comprising full-blown epistemological relativism: i) non-cumulativity; ii) theory-ladenness and underdeterminacy of data; iii) holism; iv) shifting standards of success; v) incommensurability; and vi) interests and social determinants of belief.

149 They insist on using the historical record to show the inherent subjectivity of science, the indeterminacy of the empirical data, and the inadequacy of induction. Yet their method is objective in intent, it assumes the adequacy of the data in question (historical cases) and is inductive in approach.

150 He had not moved from this viewpoint in his later writings (see his 2000 [1993], p.242).
Several salient points are revealed here: first, Kuhn’s attempt to avoid the awkward relativist charge has proven unsuccessful, and what the relativist ‘loses’ is precisely what is disputed. Realists argue that much is lost with respect to explanation, rationality and objectivity in science. Secondly, the wish to shift the meaning of “progress” in science strictly towards empirical success or adequacy—that theories are to be evaluated solely as instrumental tools (a typical anti-realist move, also bolstered by Van Fraassen). This entails that the theoretical entities and/or laws which theories contain (e.g. atom, electron, field, element, gene, species, etc.) are fictitious and do not refer to real objects\textsuperscript{151}. Thirdly, Kuhn’s position resembles the arguments of others, including postmodernists and philosophers who have made the “interpretive turn” (e.g. Rorty, 1979)—those who explicitly reject the correspondence theory of truth. They seek instead to substitute ontological representation with constructivism and truth correspondence either with coherentism (or meaning holism) or truth pragmatism. However, these are equally disputed positions (which unfortunately cannot be addressed here).\textsuperscript{152} Fourthly, there is exhibited a strong tendency to view theories and scientific knowledge as tightly correlated with the mental constructs limited to scientists (or the scientific community). It is one thing to say a scientist’s perception is constrained to the limitations of his theory’s perspective, its underlying ontology and community tradition. It is quite another thing to insist that a world independent of scientific belief, perception and community (theory, theory-laden data, epistemology and sociology) is impossible to ascertain. As Nola (1988, p.13) has pointed out: “a realist can well agree with the claim that we are active makers of our theories but reject, correctly, any implication that we are active makers of what our theories are about”. Lastly, note that Kuhn’s exploits the historico-inductive argument (a kind of inference to the best explanation) using historical evidence to disconfirm realism.

\textsuperscript{151} There are inbetween positions. Nancy Cartwright in her important (1983) \textit{How the Laws of Physics Lie} accepts the existence of entities but maintains anti-realism for laws. She qualifies this by distinguishing between phenomenalological laws (i.e. as in applied physics and engineering) and fundamental laws (the typical generic and famous theories in physics and chemistry as found in textbooks). She maintains that while the former are fairly accurate at describing how bodies behave (are “true”) they nonetheless remain restricted in scope and hence trade off explanatory power for truth. The latter suffer the opposite defect in having wide explanatory power but lack truth because they cannot be used in specific real case instances. Note her position is somewhat a reversal of the earlier mentioned phenomenalological views of science.

\textsuperscript{152} Briefly, the contextual or holistic theory of meaning holds that the meaning of any one term is dependent upon its internal relation of all other terms (or beliefs), which hang together in a kind of semantic web. To change any one term’s meaning is to send a “ripple effect” throughout the entire web, substantially affecting the meaning of all terms. Thus the meanings of terms are connected to the surrounding context. Strong versions of both correspondence and coherentism have serious defects and their weaker forms are usually easier to defend. Quine, Kuhn and Feyerabend all adhere to strong versions, as do relativists. Realists are divided as to whether or not realism entails a prior commitment to truth correspondence (Psillos, 2000). Devitt (1984), for example argues that while realism and truth should be addressed as distinct problems, realism in order to be viable requires some form of correspondence.
In general, Kuhn and other authors often employ three arguments to buttress their anti-realist claims: *anti-rationality* (that choices for paradigm change are not firmly grounded in epistemic reasons but largely determined by social factors and power, or personal idiosyncrasy, aesthetics, persuasion, etc); *incommensurability* of rival high-level theories (meaning holism, meaning variance; logical non-reduction; non-translation; indeterminacy of data); and the aforementioned *inductive historical* argument. These arguments though related can be separated and dealt with individually.

It was Kuhn himself who later came to differentiate the first two arguments. He had been stung by the “relativist” and “anti-rationalist” charges and sought to reaffirm to his skeptics (and later against some sociologists of knowledge; Kuhn, 2000; Nola, 2001) that his insistence the scientific enterprise as he had conceived it was indeed *rational* and hence in its special way “objective” because of certain universal “values” or “standards” (the older positivist view would have preferred “rules”) shared among the scientific community when assessing empirical evidence and competing theories. Yet McMullin (1993) and Laudan (1984) have conclusively shown, I believe, that Kuhn has seriously underestimated the epistemic force such values have, especially when scientists analyze perplexing (rare) cases of rival theories (and where the data remains underdetermined) and must play off *explanatory power* against *predictive accuracy*. Hence this raises “a serious question about the adequacy of an instrumental construal of the puzzle-solving metaphor,” argues McMullin (1993, p.132). He concludes: “The Kuhnian heritage is thus a curiously divided one. Kuhn wanted to maintain the rational character of theory choice in science while denying the epistemic character of the theory chosen” (p.135). Worse for Kuhn, much worse, is that both authors have themselves used historical-based inference by turning to the historical record to shore up their arguments, the exact basis he maintained established, and would continue to establish, his theses. The argument of *incommensurability* (and *meaning variance* of scientific terms over time) is complex and

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153 “By separating the issues of comparability [i.e. rationality] and commensurability [i.e. anti-realism], he believes he can retain a more or less traditional view in regard to the former while adopting an instrumental one in regard to the latter. The radical challenge [in his book *Structure*] is directed not at rationality but at realism” (McMullin, 1993, p.132).

154 “Neither the history of science nor Kuhn’s philosophical arguments show that scientific revolutions cannot be resolved by rational arguments based on evidence and shared rules. By treating paradigms as indivisible wholes and failing to appreciate the ways in which rules and aims can be rationally debated, Kuhn has seriously underestimated the role of reason in paradigm debates . . . Thus, according to McMullin and Laudan, Kuhn’s thesis that subjective, psychological, and rhetorical factors must play a *leading role* in all scientific revolutions is ill supported and false” (Curd and Cover, 1998, p.239; my italics). See Pyle (2000) for a critique of the Kuhnian historical interpretation of the chemical revolution of Lavoisier.
unresolved, and cannot be appraised here.\textsuperscript{155} Suffice to say that it presents a serious challenge to scientific realism and rationality.\textsuperscript{156} Although scholarly consensus now holds that rationality has been recognized across revolutionary divides (as discussed), realism has \textit{not} therefore been satisfactorily confirmed. This philosophical doctrine is provided as an \textit{explanation} of the alleged conceptual incompatibility of successor theories to earlier ones (e.g. Einsteinian versus Newtonian mechanics), and thus indirectly of historical developments in theory (paradigm) change, and so, once again we have here an appeal to the historico-inductive argument and thus, by way of inference to best explanation (IBE), to anti-realism.

In short, the historical IBE argument against realism can be formulated along two different but interrelated lines. One line focuses on that aspect of incommensurability relating to \textit{meaning variance}. It argues that because the \textit{meaning} of central terms in a theory (like ‘electron’, ‘atom’, ‘heat’ or ‘mass’) undergo radical conceptual revisions, even \textit{meaning loss} (while other terms are simply revised or dropped), during paradigm shifts (\textit{revolutions}) the existence or ‘truth’ of such terms cannot be assumed, especially since such terms allow neither for inter-theoretic translation nor reduction. Quine, Kuhn and Feyerabend argued to differing degrees in this vein, where they interwove the interpretive meaning of these terms to the \textit{contextual holism} of the theory structure, within which such terms were tightly embedded, along with the scientific community’s socially-active construal. Hence the postulated entities derived their ‘reality’ mainly from relations in a given and historically contingent theoretical (and social) framework, along with congruent rules for empirical utility, and less so from their conjectured connection to an extra-theoretic reality to which they were said or assumed to refer.

\textsuperscript{155} Forster (2000, p.245) agrees. The \textit{Incommensurability Thesis} developed along two separate lines: one was defined by Quine and based upon considerations in the philosophy of language; the other was defined independently (but almost simultaneously) by Kuhn and Feyerabend and based upon considerations in the philosophy of science. Kuhn, too, under criticism, had later come to modify his own thesis and aligned it with Quine’s \textit{untranslatability} thesis, though with differences (Kuhn, 1982). Sankey (1994) has provided a comprehensive and critical account of the two versions of the thesis. See also Bird (2002) for a negative and Brown (2005) for a more constructive assessment.

\textsuperscript{156} "The problems of rivalry, content comparison, and progress are the most important issues raised by [the] thesis. They represent a challenge to the rationalist seeking to understand theory-choice as informed by a critical appraisal of genuinely alternative theories. They are a challenge to the realist inclined to view theory-change as resulting in an increase of truth about the world" (Sankey, 1994, p.4). With regard to Feyerabend’s version we read that his “conception of meaning and his skepticism toward the ontological implications of scientific theories presented a serious challenge for scientific realism” (Arabatzis, 2006, p.244). Bird (2002) however maintains that the thesis no longer presents the danger it once did and has since lost its "philosophical significance" for most philosophers of science (p.444). Sankey (ibid, p.221) holds a similar view: "If we like, the word may be retained as a loose name for the cluster of related problems having to do with theory change." Arabatzis alternatively, considers the challenge posed by the meaning variance aspect of the thesis as quite serious, and one that \textit{must} be met by realists.
The second line of attack is represented by Laudan’s (1981) famous assault on “convergent realism”, the widely held view that realism presents the best argument for the success and progress of science. This is due to the fact, the proponents argue, that current theories are (empirically) successful by virtue of them being true (or at least “approximately true”), and hence, as theories have replaced one another over (historical) time they have “converged towards truth”. Because his critique has been called the “pessimistic meta-inductive” argument (Ladyman, 2002; p.236), his strategy was essentially one of turning the realist’s “optimistic” IBE historical argument on its head because older successful theories (empirically accurate ones) contained entities now shown not to refer (or exist) and because these theories are today said to be wrong and discarded (“ontological elimination”: phlogiston in chemistry; celestial spheres and epicycles in astronomy; ether theories in physics, and many others), by the same token, he argues, our present best and successful theories (like relativity and quantum mechanics), which are no different in kind, in all probability will suffer the same fate in future. Hence one cannot take their posited entities as “real” and one should not believe in their “approximate truth”. Therefore the so-called “best argument” of the realists is nothing of the kind. On this view science is successful not because it “tracks truth” but on the contrary (just) increasingly develops empirically adequate theories—and utility does not argue for truth.

These two lines of argument, the attack on convergent realism and meaning variance represent, I believe, the best cases to be made for anti-realism which must be confronted head on and rebutted by realists. Science instructors should also be cognizant of them for two important reasons: a negative one, in that they fly in the face of popular beliefs of science and can be easily misused by anti-science popularizers; and a positive one, in that they help inoculate against naïve views of realism, inductivism and progress.

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157 This is has come to be referred to as the “no miracles argument” for realism. Putnam helped establish the slogan when he argued in 1975 that “[i]t is the only philosophy of science that does not make the success of science a miracle” (quoted in Psillos, 2000, p.715).

158 Most scientists take this traditionalist view as self-evident. A typical example here is the embryologist Wolpert (1992). His case is unusual however in so far as he is intimate with the writings of philosophers of science like Kuhn and the relativist arguments of some sociologists. Moreover, he presents many historical case studies to buttress his conclusion (p.100): “But it is precisely in this respect that science . . . is special: for the history of science is one of progress, of increased understanding . . . And in the last fifty years the progress in, for example, understanding biology at the molecular level has been astonishing. Science is progressing in that the truth is being approached, closer and closer, but perhaps never with certainty. But very close approximation can be a great achievement and is infinitely better than error or ignorance.”

159 Kuhn, as cited earlier, had maintained that scientists and people in general tended to this popular outlook because of (mis)education and the falsified histories in textbooks. Laudan in effect reinforces this.
which dominate current beliefs, textbooks and traditionalist pedagogy (scientism). Let me then quickly describe how as an educator one could proceed.

It is probably best to shun technical talk of “incommensurability” but meaning variance cannot be, I think, ultimately avoided. Consider the case of comparing key theoretical terms like “mass”, “length”, “time” or “gravity” in Newton’s and Einstein’s theories, as commonly presented in secondary and tertiary instruction. Usually one is told that Newton’s theory while having been “superceded” by Einstein was “not entirely wrong”, and Einstein’s theory is “more correct” in having “expanded the range” outside the confines of Newtonian theory. Indeed the older theory can be shown to be a “special case” of the newer in certain limiting instances, such as, for example, in the limit of low velocities the equations for calculating “mass” in special relativity reduce to Newton’s formulations. The student is given a picture of the cumulative growth of knowledge, of simple progress both towards “truth” and of greater predictive accuracy, of a smooth transition between the two theories, of meaning invariance of mass, perhaps even of a “crucial experiment” (Michelson-Morley) “proving” the classical ether and its assumptions of space and time decisively refuted.

Unfortunately all of this is a myth and the student has been plainly miseducated. Both Kuhn and Feyerabend can be credited for having correctly drawn attention to this, especially with versions of this example (which they both cite, as does Van Fraassen), that central terms like “mass” cannot be understood outside of their defining theoretical context (holism), and that they do not co-refer to the same empirical object (although on the surface it appears that way; it will be admitted this interpretation is contentious). In each theory the terms have fundamentally different meanings and this fact should be made explicit and not glossed over. While it is true that the two theories reduce in mathematical form there is no reduction in their two differing ontologies, and the usual quick instructional move in equating them reveals a deep-seated misunderstanding of the nature of the two physical theories (Schulz, 1990). And while the Michelson-Morley

\[160\] The ontological picture is in truth much more complicated and damaging for realists than I have made it out to be. Classical mechanics comprises at least three distinct and incompatible ontologies within its historical formulation. First, the original theory of forces acting at-a-distance; secondly, the field-theoretic approach which understands gravity as a field (potential) occupying all points in space, acts locally and is analogous to electromagnetic field theory (also related to modern gauge field theories and, to some extent, to Einstein’s radically transformed gravity field in general relativity). Thirdly, the “analytic mechanics” approach developed by Euler, Lagrange and Hamilton in the 18th and 19th centuries, based on the “principle of least action” and the energies of the system (of masses). (Einstein’s theory thus presents a fourth ontology). One assumes these three classical ontologies represent different formulations of the same theory only at the cost of holding to an anti-realist (positivist) view since all three are empirically equivalent, although not evidentially equivalent. Such an equivalence is commonly and explicitly presented in tertiary physics education although they “refer to different entities and posit different explanatory frameworks”
experiment did reveal inconsistencies in the guiding assumptions of classical mechanics it historically did not play the role often attributed to it as a Popperian-type falsification instance (Brush, 2000).

It is equally difficult to see how this far-reaching conceptual revolution in physics can be understood as a case of "progress" in terms of convergent realism. Especially when one considers that Newtonian classical mechanics was upheld for centuries as the "true" picture of nature, where for Newton "gravity" denoted a real universal force operating between actual masses (and allegedly confirmed by Cavendish's experiment one hundred years later), whereas for Einstein gravity (in General Relativity theory) is clearly an illusion created by the space-time curvature around a massive object. Force as the universal glue holding the cosmos together had been demoted to a mere fiction. Both theories, moreover, made novel predictions, could explain laws (thus had wide explanatory power) and have great empirical success. Any of the other oft-mentioned "values" could also be applied to both (such as simplicity, fruitfulness, coherence, etc.). And scientists, usually thinking along convergent realist lines, sometimes describe Newton as being "false" and Einstein as "true" or at least the "more correct" theory of nature. It seems to me, that cases such as this are worth their weight in gold for anti-realists like Van Fraassen, and hence his position of agnostic "constructive empiricism" appears the more reasonable one.

But this is by far not the end of the story. This mass variance example does support Kuhn and Feyerabend's interpretation that some key terms must undergo meaning variance, and the case for weak incommensurability. But one swallow does not make a summer. Other research involving the problem of reference of theoretical terms and historical case studies suggests that meaning and reference is indeed theory dependent, but not necessarily in the wholesale way the theory-laden thesis and coherentism demand. ¹⁶¹

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¹⁶¹ This does not mean we can go back to the earlier causal theory of reference-fixing by such semantic realists as Kripke and Putnam, although philosophers like Bird (2002) often enlist them against Kuhn and company. "Both views err in opposite directions; incommensurabilists permit wholesale referential change, while those who hold to a bare causal theory permit little, if any referential change. Moreover both views conflict with standards accounts of the historical stories told of scientific revolutions. In these accounts, some terms retain their reference, others change their reference, new items are introduced to refer to new entities and old-terms previously thought to refer are declared non-referring" (Nola, 1980, p.527). Nola had reached this conclusion by studying the historical cases of the revolutions associated with the theory of electrical attraction ("effluvia") and the theory of combustion ("phlogiston"). Aratazis (2006) presents several weaknesses in the arguments used by Putnam against the well-known Feyerabendian theses.
Arabatzis (2006) has carefully studied not only the historical record concerning the term “electron” and its varying *representations* (and models) in the crucial era between 1890 and 1925 but also examined the philosophical presuppositions of historiographical writing. (Most people may be surprised to learn that the *notion* of the electron is by no means an obvious one and engenders some debate in HOS and POS circles, despite its indispensable and indisputable role behind so much modern technology, including electricity, communication, and older computer and TV cathode ray screens). He has discovered, quite surprisingly, not only that *representations* in physics tend to take on a life of their own—that they exhibit a certain autonomy—but more importantly a “core of meaning survived changes in theoretical perspective” (p.262). What has been revealed therefore with studies in the history of science (HOS), whose significance has moved to the fore in philosophical debates, is that the *historical-inductive argument* cuts both ways, and cannot just be used as a weapon in the anti-realist arsenal. It is necessary albeit not sufficient for realism that “the core of properties attributed to the entity will survive changes in high-level theory” (p.258).

*How should an educator then approach the problem of meaning variance in curriculum?* Recall that the instructor must already be cognizant of meaning variance because of how ideas are learned and understood within a conceptual web of meaning, and that these are tied to a given scientific theory’s ontology. Recall as well that students have difficulty with learning isolated concepts and especially ontologies too far removed from their everyday experience. Studies in POS have also shown that scientists during times of conceptual change (during revolutions in particular) have difficulty making the transition to a new ontology in which some key terms either lose their meaning or have them redefined. Educators must now be additionally cognizant that when the curriculum happens to shift across a revolutionary divide (e.g. when expected to teach about special relativity or quantum mechanics or evolution) they must verbalize and clarify that some formerly familiar terms have now suffered meaning losses, although the degree to which they suffer, whether radical or gradual, can be left open, and admitted as uncertain due to academic dispute. In other words, scientific representations, and allied with them their

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162 “Throughout that period nobody doubted that the electron was a universal constituent of matter, with a certain mass and charge, and that it was the agent of radiation ... This aspect of the construction of the concept of the electron supports, albeit not conclusively, a realist attitude towards the electron” (ibid.).
“Any future theory about ... electrons will have to incorporate, but perhaps also reinterpret, these ‘well-known causal properties’ of electrons” (ibid., p.257; my italics).
163 Arabatzis (p.260) concludes “historical case studies can play a dual role, either negative or positive, in disputes over scientific realism. They can either undermine realist intuitions or neutralize the antirealist implications of meaning change. However, this neutralization does not lead automatically to a realist position.”

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models (electron, atom, gene, chemical bond, etc.) can retain a core of meaning (tied directly to measurable features), even as they undergo sometimes drastic revisions over time when theory ontologies change.

Coming now to the anti-realist argument against convergent realism, realists have tried several strategies to counter it. Some like Devitt (1991) think Laudan’s historical examples are overstated and can be (easily) met; others deny him that our best current (“mature”) theories are no different in kind, or that Laudan’s conception of “empirical success” is too flexible and does not accommodate cases of novel predictions for confirming or adjudicating among theories (Ladyman, 2000, pp.238-243). Hence “it is arguable that contemporary science has a degree of unification and coherence, as well as mathematical sophistication, that is quite absent in many of [the] theories Laudan cites” (ibid., p.238). I think this argument is only partially valid for some of his examples. Laudan has correctly countered that the theory of the electromagnetic ether was a “mature theory”, and the argument is clearly invalid for the case of classical mechanics. Newtonian physics (a “mature science”) clearly displayed all such aspects and is now considered in most lights as false (although it is still used). Others, such as Psillos (1999) take him more seriously and meet him on his own ground, by seeking to undermine the historical argument by restricting the number of falsified theories and entities which form his inductive base, and/or showing continuities with respect to those aspects of abandoned theories which contributed to the success of newer ones. Hence although

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164 Matthews (1994, p.177) even cites Devitt to the effect that the problems raised about verisimilitude “can and have been answered”. I could not disagree more. The arguments Devitt presents on pp.161-174 cannot be considered as decisive refutations in my view, especially his reliance on partial reference when comparing the Newtonian and Einsteinian discontinuity (p.165) or his critique against incommensurability (p.168). He certainly does not argue from historical evidence, rather from philosophical premises.

165 "If the relevant realist arguments are sound, then the fact that our current best theories may well be replaced by others does not, necessarily, undermine scientific realism. All that it shows is that a) we cannot get at truth all at once; and b) our inferences from empirical support to approximate truth should be more refined and cautious in that they should commit us only to the theoretical constituents that do enjoy evidential support and contribute to the empirical success of theories" (Psillos, 2000, p.721). The examples of abandoned theories, however, are much more serious an instance against realism than cases where previous theories have been "absorbed" into other theories, with some entities either redefined or dropped (e.g., Newton into Einstein). Such cases are primarily about meaning variance and although difficult, as discussed, they are not about ontological elimination, such as phlogiston theory, which even Devitt (1984, p.161) admits presents a strong case. This is a major difference in kind. Neither Ladyman (2002, pp.244-252) nor I have been convinced that Psillos (1999) has effectively met the test posed by Laudan’s historical counter-examples of the caloric theory of heat or the electromagnetic ether theory of light. Both of these were mature and enjoyed novel predictive success. “Even if there are only one or two such cases, the realist’s claim that approximate truth explains predictive success will no longer serve to establish realism” (ibid., p.244), precisely because the theoretical entity and the entire ontology has been dumped. Here the "relevant realist arguments" as presently structured do not appear to be sound.

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“truth” *per se* may not be salvable, notions of convergence in terms of “approximate truth” can be.

Notions of “progress” in terms of “approximate truth” however are notoriously difficult to explicate and philosophers have raised several problems with them. While most realists concede that Popper’s earlier “verisimilitude” version is unsalvageable, Psillos (2000), Boyd (1983) and others (Newton-Smith, Putnam, Matthews) maintain some such concept is mandatory to sustain realism, which I think is correct. Yet Laudan (1981, p.1124-5) has charged that the notion is too ill-defined to serve the purposes to which it is put and further, this lack of clarity undermines the realist’s cause. Aronson *et al.* (1995), attempt to rescue the idea with the epistemic notion of *similarity* with respect to models and theories as type-hierarchies of natural kinds. Giere (2004), in a similar vein but on a more restricted path, argues that a sufficient case can be made (while evading “truth-likeness”) employing the notion of “similarity” related to how *theoretical models* approximate (and can be tested in) the domains in which they are applied. 166 There is currently much discussion going on in this line of research and they bear directly on science education in very practical ways. This includes how students can learn science through *model-based reasoning* that can help facilitate conceptual change (Schulz and Sivia, 2007), as addressed in some cognitive science studies (Nersessian, 1998, p.163). Hence there could be a double payoff for education in so far as model-based reasoning would help students learn (and reason) as well as illuminate scientific epistemology (by seeing how science “tracks truth”).

Use of the terms “model” and “theory” within the science curriculum should, therefore, be an indication of the “degree of certainty” with which we hold a particular view. It is quite common in school science to have a realist theory (for explanation) and an instrumentalist model (for prediction) for the same phenomena. Nor is it unknown to have alternative, conflicting instrumental models for different aspects of the same phenomena (e.g., wave and particle models of light). What is confusing for children is that the role and status of theories and models are not defined (Hodson, 1991, p.24).

166 Giere’s view is that to the extent to which the model and the real system are similar, we may say that the model provides a better or worse approximation to the real system. He suggests that the notion of similarity between models and real systems provides the resource for understanding approximation in science and avoids ‘the bastard semantic relationship’ of approximate truth” (Psillos, 1999, p. 273). Psillos while strongly supporting Giere’s approach nonetheless maintains Giere’s abandonment of “truth-likeness” is premature. He argues for the retention and defense of this concept, even—and especially—in light of Laudan’s familiar attack on it, and that Giere can hardly avoid some use of this notion. Giere’s revised conception of the *aim* of science is given in (2005, p.157): “The aim of science is not “a literally true story of what the world is like,” but merely the production of models similar to limited aspects of the world in ways determined by the scientific context. Some of these aspects may be of the type traditionally designated as “theoretical,” such as the atomic structure of the air.”
In conclusion, one can reasonably maintain that modern science is a successful and rational enterprise with reliable—but never absolutely certain—knowledge and whose theories, entities and laws are well confirmed (Haack, 2003; Bird, 1998). What then of realism and “truth”? Although both philosophical doctrines associated with realism and antirealism have their respective weaknesses and problems, in order for science to empirically advance—even in ways strict instrumentalists would accept—appears contingent upon the strong belief among scientists (see Weinberg, 1992) that their theories are approximately true and convergent (which most anti-realists but not positivists can assest). Clearly there is a difference between the “correctness” and the “utility” (or productivity) of a belief (Elby and Hammer, 2001). Alternatively, scientists can be, and often are, quite skeptical about the truth-value of their constructed models (Forster, 2000). Moreover, the epistemic estimate of the truth-value of scientists’ theories is only really contentious with strict forms of empiricism (which bear their own problems), notably with theoretical constructs or entities (unobservables) and this primarily raises questions about their possible fictive makeup only for those few (of the many) sciences focused on explaining phenomena associated with the micro- and macro-realms, like particle physics, molecular biology, quantum and structural chemistry, or astrophysics and cosmology.\(^{168}\)

If discarded theoretical entities and mechanisms—crystalline spheres, phlogiston, humors, etc.—are a problem for realists, then the long litany of such entities that have been effectively revealed and scrutinized is a bigger problem for empiricists. One-time theoretical entities—molecules, electrons, genes, chromosomes, molten cores, the planet Neptune—have a habit of turning into respectable observable entities. The empiricist doctrine is predicated upon a distinction between observation terms and theoretical terms that the advance of science and technology renders untenable (Matthews, 1994, p.178).

Be that as it may, the controversy about convergent realism remains unresolved and continues to be fleshed out according to the views, arguments and proclivities of the

\(^{167}\) A remarkable fact about modern science is that as the number of phenomena which science has investigated has grown, the number of theories needed to explain them has decreased. And those theories have been deeper and more general, and, correspondingly, more integrated when it comes to explaining the phenomena. ... From the point of view of the constructive empiricist, who thinks our theories are empirically adequate to the phenomena but are most probably false, this fact should not be merely remarkable but really quite extraordinary ... the ability of a theory to integrate with other theories and its ability to produce novel and unexpected true predictions constitute evidence for its truth that goes beyond observational success” (Bird, 1998, p.150). Haack would agree with this view, but is more fallibilist.

\(^{168}\) This likewise raises the contested thesis as to the conjectured inter-theoretic reduction of the sciences, either within or across disciplines (e.g. biology to chemistry to quantum physics), which some philosophers of biology and chemistry increasingly question (and cannot be addressed here). They deny such reductive assertions are ultimately required to yield predictive success and that there exist autonomous levels of explanation (refer to Kitcher, 1984, against inter-biological reduction, and Scerri, 2001, against the oft-asserted chemistry reduction to quantum physics). Weinberg (1992) remains a champion of reductionism.
contestants, and one must give careful ear to how terms like “success” and “progress” are given various, even contradictory meanings: anti-realists and relativists (Kuhn and others) assert that contrary to the traditional understanding of science (as continuous, but non-linear and cumulative), it does “progress” but only as a more adept instrument for problem-solving and empirical “success” and not towards “truth”. It is discontinuous and non-cumulative. Others, such as Nersessian (1998) maintain progress during conceptual change is continuous but non-cumulative, while realists like Brown (2005) hold it to be continuous, but non-linear (and cumulative), and pragmatists like Laudan (1990) insist science is progressive but non-cumulative. All these authors have availed themselves of historical case studies and examples to defend their views. *Educators can therefore no longer assume for NoS a non-problematic continuous and cumulative character.*

*How should an educator then approach the problem of “convergent realism” in the curriculum?* As with the previous case of discussing meaning variance educators can mention that while scientists may believe their theories converge on truth, whether or not they do—and *how* they do—is a matter of much dispute, and that the historical record shows not a smooth progression but rather a continuous but non-cumulative growth in our theory-based knowledge and views of nature. Yet neither has “progress” been so discontinuous or disjointed that it has not allowed for a significant improvement in either the empirical accuracy of our theories or our overall understanding. In effect, during revolutionary changes some “knowledge” is lost, some revised, while new insights are gained and new predictions and advances made. Alternatively, though current ontologies appear to “match” nature better than previous ones (as in “best-fit” scrutiny) there is no guarantee such a “match” will not be superseded and hence our understanding could be radically altered in the future. This is the crux of the slogan that all “theoretical” knowledge is *tentative*. In spite of this, this awareness should not be allowed to cloud the very certain and non-tentative character of established “factual” knowledge—i.e. the “facts” (very rarely are these discarded): one thinks here of the existence of the cosmic constants and their peculiar values which cannot be accounted for: speed of light c; Planck’s quantum h; electric charge e; and Gravitational constant G; or the circulation of the blood, or that most massive objects near the earth’s surface accelerate at a constant average rate of 9.8 m/s².¹⁶⁹ *That objects fall at a certain rate is undisputed and not affected*

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¹⁶⁹ One should also include in this list true *discoveries* of entities like x-rays, electrons and neutrinos, and especially the accumulation of empirical laws, like Kepler’s 3 laws of orbits, laws of thermodynamics, etc. For the latter even Kuhn himself explicitly admits the importance to acknowledge the non-tentative and cumulative nature of this empirical base: “As science develops, they may be refined, but the original versions remain approximations to their successors, and their force is therefore either obvious or readily recaptured. Laws, in short, to the extent that they are purely empirical, enter science as net additions to
by changes in high-level theories, though the explanations as to why and how they fall depend on the theoretical framework, which can change (e.g. interpretations of the meaning of “gravity” in Newtonian classical mechanics (force) versus Einstein fictive).

The issue as I see it for those in science education is not just to clarify “the role and status of theories and models”, as important as that is, but likewise one of taking seriously the nature of scientific revolutions and hence to clarify them as well (as Duschl, 1990, has sought to do). Thus the problems of assessing how strong or tenuous are the continuities (meaning variance), or how deep the discontinuities (ontological elimination) across the revolutionary divide (of paradigm shifts). This important feature of scientific development can no longer be ignored or glossed over in curricula and instruction, when and where revolutions appropriately arise with content knowledge (CK). This sadly has taken, and continues to take place not only because of pseudo-historical narratives but also due to the prevailing philosophical bias that science because it is understood to be (assumed to be) continuous and cumulative such atypical upheavals can be avoided, at worst, or given lip service, at best. (No doubt the two have reinforced each other). It is not satisfactory for cross-national Standards documents to agree and simply state that NoS involves both “evolutionary” and “revolutionary” changes (refer to p. 133) without elucidating the chief differences involved here. This is especially true when traditionalist curricula continue to privilege the former while demoting the latter, as is typically done when the “growth and development” of ideas is discussed and in essence viewed through a kind of extended “normal science” frame that fatally glosses over the discontinuities of revolutions (Siegel, 1979; Kuhn, 1970).

The HOS case of the Copernican revolution (Kuhn, 1957/85) is an excellent example where much has been neglected (rarely mentioned as a “revolution”, and if so hardly clarified), and much can be done to reform science pedagogy: here key philosophical issues can be addressed, and it happens to be one case that I myself have used. It gives rich material for the student to learn about: underdetermination of data for rival theories (Ptolemy versus Copernicus); the use of models to “fit data” for phenomena in specific domains along with reasoning using inference to the best explanation (IBE) (Kepler’s analysis of the three models of Ptolemy, Copernicus and Tycho); the meaning variance of key terms (like “planet”, “star” and “motion”); and the controversy about the merits of their relative realist or instrumentalist interpretations. They even learn that abandoned theories (Ptolemy) can still contain models which retain their instrumental value (e.g. the earth-centered celestial sphere is still used for GPS navigation and by

knowledge and are never thereafter entirely displaced” (1977, p.19). Unfortunately this important admission is little known among his many supporters and relativist-inclined defenders.
NASA). It could include discussions on how theories impact upon the cultural and religious views of society at the time, and more importantly spotlight how with Kepler (and later Newton) explanatory power outweighed mere empirical adequacy and predictive success (McMullin versus Kuhn), and finally helped ground the theory without question on a realist base. Once again the advantage of a critical realist position vis-à-vis instrumentalism can be acknowledged.170

4.8. Summary
The common academic paradigm structures epistemic content knowledge (CK) of the school curriculum in an ahistorical (often a pseudo-historical) and decontextualized fashion (“scientific meaning”) which basically cuts the student off from the ability to construct meaningful learning (“contextual meaning”) and gain a deeper insight not only of the concepts being employed but especially the nature and development of scientific knowledge. Empirical findings have shown that such a pedagogy overwhelmingly presents an obsolete image of science because it lags decades behind the newer studies in history, philosophy, and sociology of science. Research has uncovered that among both teachers and students fundamental misconceptions exist (i.e. their personal epistemologies) about the nature of science (NoS), especially pertaining to their understanding of its epistemology and methodology. There is little awareness of the precarious nature of cutting edge scientific research and the role of human imagination and creativity in knowledge production nor attentiveness to the vital difference between the evolutionary and revolutionary developments of scientific concepts and theories. Science education in general fails to adequately explicate the distinctive character of laws, models and theories at the core of explanation.

Much of the confusion can be laid at the door of the nature of specialist textbooks and the mistaken “scientism” inherent to school science epistemology as well as the failure of helping teachers develop a philosophy of science education as a second order reflective capacity. Such a philosophy as part of a teacher’s pedagogical content

170 Critical realists can be realist about some theories (those they believe to be true) and instrumentalist about others, which they find useful but not true (i.e. theoretical models). Instrumentalists, however, are always instrumentalist and have no need to distinguish between theory and model. From the critical realist position, it is not illogical to retain a falsified theory in an instrumental capacity, provided that its status is acknowledged. The fact that it is useful does not mean that it is true. It may be that within a restricted domain of application a falsified theory is more useful than a true one because it is simpler to use. Science often approaches a realist theory by way of tentative instrumentalist models and may retain a structure in an instrumentalist capacity (i.e., as a convenient model) after its realist value has eroded” (Hodson, 1991, pp. 23-4).
knowledge (PCK) would seek to broaden the view of content knowledge and incorporate HPS insight to critically examine curricular materials and helping transform instruction. Scientism was recognized to encompass five tenets and linked to other myths typically presented in precollege and college science pedagogy. It was also associated with objectivism as part of the wider epistemological foundationalist project of the Western Enlightenment, although foundationalism itself has been widely renounced, and science itself was never established on a foundationalist basis. “Textbook science” according to Kuhn and according to investigation is preoccupied with promulgating “normal science” or the reigning theory and paradigm of the day with little to no concern about how and why that theory had become established. Presented historical accounts are often mythical, because “normal science” ignores “revolutionary science” by systematically distorting and disguising the historicity of concepts and theories. This forces education into both a moral and an epistemological dilemma. The student is asked to accept this knowledge on the basis of the authority of the teacher and the text (with whatever slim evidence is presented therein), without really knowing the grounds for the legitimacy of that authority—a type of pedagogical dogmatism. HPS reform ideas argue for better inclusion of nature of science with a revised epistemology (including emphasizing scientific reasoning), and while academic dissensus exists over nature of science (NoS) a minimum of common ground can be articulated at the school level. A range of NoS discussion can be articulated from a minimal base to more sophisticated views dependent upon grade, course, and the age-developmental stage of the learner. Finally, a case study examined the realist-instrumentalism debate in philosophy of science, counting Kuhn’s views, as an example of how a philosophy of science education could provide clarity for educators and contribute to overcoming naïve realism while developing a critical realist outlook.
CHAPTER FIVE: Philosophy of Science Education and Nature of Language

"Each science, as a science, has in advance projected a field of objects such that to know them is to govern them. We find quite another situation when we consider man’s relationship to the world as a whole, as it is expressed in language ... For to live in a linguistic world, as one does as a member of a linguistic community, does not mean that one is placed in an environment as animals are. We cannot see a linguistic world from above in this way, for there is no point of view outside the experience of the world in language from which it could become an object ... Being that can be understood is language ... Thus hermeneutics is ... a universal aspect of philosophy, and not just the methodological basis of the so-called human sciences” —Gadamer (Truth and Method, pp. 449; 471)

5.1. Introduction: the Shift from Epistemology to Ontology: the “Interpretive Turn” and Hermeneutics

In the discussion so far two fundamental theses for improving science education have been raised and defended: the value of Egan’s metatheory as an overarching conception for the educational endeavor (also as practical planning framework) of teaching and learning science subjects ("science literacy") as well as for informing the educational philosophical component of a science teacher’s PCK; and secondly, the value of surfacing epistemology and nature of science (NoS) for broadening both a teacher’s CK and a student’s understanding of science subject development. The first addresses the “why”, “when” and “how” to teach from a predominant educational theoretical perspective, arising from considerations in the philosophy of education. The second addresses the “what” to teach (and encompassing the “why”) by enabling a critical perspective on curriculum and textbooks arising from considerations in the philosophy, history and sociology of the sciences. As mentioned previously, the common formal content of science discipline subjects must be taken as problematic by the teacher when curriculum planning and teaching for two reasons: it requires an adequate transposition for learning purposes (Egan) and it requires an adequate curriculum broadening to include NoS for more inclusive and accurate science comprehension purposes (HPS). The duty of a PoSE, it has been put forward, is to offer critical and reflective platforms for enabling both of these to take place in general, even though I have also suggested specific ways to address them, by fronting Egan and HPS.
It can be admitted that these two tasks are certainly challenging and comprehensive enough for science teachers to consider when unit or lesson planning in their classrooms, and for training programs in Education Faculties to accomplish with aspiring teachers starting out afresh and wishing to enter the profession. I would agree that these two tasks taken alone would go a considerable distance in improving contemporary science education, as some studies that have focused exclusively on NoS inclusion have already shown. But there is one more significant component, however, which has come to prominence relatively recently in science education research circles that must be considered when discussing science education reform—the nature of language (NoL) and its involved and often hidden role in science learning and NoS understanding. This additional component therefore represents another dimension of science education that a “philosophy of science education” must deliberate upon and scrutinize. To clarify at the outset, however, my emphasis and contribution to this discussion of NoL will avoid the “philosophy of language” debates typical to Anglo-analytic philosophical discourse, and avoid in general a comparison of language philosophies in the two traditions (Anglo-American and Continental-hermeneutic; see Medina, 2005). My interest is to pursue the recent language discourse as found in the research literature pertaining to learning science in classrooms, but chiefly from a hermeneutic language perspective and bearing in mind the critiques of the Anglo-analytic tradition by Rorty (1979) and Wittgenstein (1953).

The central importance of language for science teaching and learning has now become widely recognized within the research community and since the 1990s the literature on this subject has grown significantly (Carlsen, 2007, Fensham, 2004; Wellington and Osborne, 2001; Sutton, 1998). Wellington and Osborne (2001) drawing on 30 years of research have provided a very useful book for classroom teachers by illustrating the importance of literacy when learning the language of science, including a discussion on how the language of science education in classrooms differs from science technical language. Kelly (2007) has provided a comprehensive review of the role of spoken and written discourse in science classrooms, building upon the earlier ground-
breaking work of Lemke’s *Talking Science* (1990). Yore and Tregust (2006) comment on the work coming out of an international conference which sought to explore the diverse research links between language and science literacy. Anderson (2007) has identified the language-focused “socio-cultural” research program as one of three major traditions on science learning that has now come to distinguish the diverse kinds of research in science education (along with “conceptual change” and “critical” traditions). Researchers within this third tradition, as can be expected, have emphasized different aspects of the role which language can play in both academic science and classroom communities, and Carlsen (2007) traces these perspectives to several leading schools of thought, notably the influence of Vygotsky, social semiotics, and studies of situated cognition within communities of practice.

The predominance however, of Vygotsky and neo-Vygotskian perspectives (Mortimer and Scott, 2000; Moll, 1990; Wertsch, 1985) on teaching and learning within the socio-cultural tradition—especially with prevailing socio-constructivist views of learning (Duit and Tregust, 1998), where Rowlands (2000) argues it sometimes misconstrues Vygotsky—along with a resurgence of interest in Deweyan pragmatism (though offering many compelling insights), have almost entirely obscured the substantial hermeneutic tradition (eminent in Continental philosophy and the humanities). Indeed, one can generally observe that there has been very little written by way of comparison in science education literature which has taken this other philosophical and humanistic tradition into serious consideration (some exceptions being Borda, 2007; Donnelly 2001; Bevilacqua and Giannetto, 1995; Eger, 1992). It has certainly largely ignored arguments of those authors, such as Rorty’s influential *Philosophy and the Mirror of Nature* (1979), who, though coming from the Anglo-analytic philosophical tradition, has nonetheless

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171 Lemke had scrutinized the discourse of science classrooms and teacher talk (especially questioning strategies) using a social semiotics perspective, including analyzing the semantic and thematic patterns of curriculum content and contrasting this to students’ questions and answers which illustrated their own thematic discursive patterns. He also noted how the typical portrayal of science attitudes and myths of NoS (enforcing scientism) contributed to alienating students from science. He was among the first to argue that “mastery of a specialized subject like science is in large part mastery of its specialized ways of using language” (p.21).
sought to more closely align the pragmatic school with hermeneutics. This chapter seeks to offer a corrective to balance out these two prevailing tendencies within science education, principally by critically re-examining the Deweyan progressivist perspective on language by identifying its serious shortcomings—which I believe several authors have glossed over or simply failed to recognize—and contrasting this with the philosophical hermeneutics of Gadamer.

Any discussion involving philosophical hermeneutics recognizes, firstly, that the modern Anglo-analytic philosophical tradition has fractured into two differing schools of thought as to what the nature and role of modern philosophy is and can accomplish (represented by the opposing views of Dummett and Rorty), and this opposition is reflected as well in contrasting perspectives on language theory—which Charles Taylor has characterized as the designative and expressive traditions (Medina, 2005, p.39). That said, many authors like Taylor (1987), Bernstein (1983) and Rorty (1979) nonetheless comment on the convergence of thinking in both the Anglo-American and Continental traditions which rejects foundationalism, or the former project of grounding philosophy, knowledge and language (“objectivism”), as Descartes, Kant, Russell and the early Wittgenstein sought but failed to do. With the current preoccupation of repudiating this formerly eminent epistemological tradition the task of “overcoming epistemology” has come to mean different things to different thinkers. Dewey (1949), for instance, sought to overcome subject/object dualism with his pragmatic focus on “transaction”, the active behaviour taking place between the knower and known. Taylor (1987) correctly views both Quine and Rorty as abandoning foundationalism (with the former attempting to “naturalize” epistemology), while he solely targets overcoming the conception of knowledge as representation that lay behind the ambition of the foundationalist project

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172 While it can be readily admitted that the “post-positivist” philosophy of science debate has been taken into consideration for some time in the research community, Brickhouse et al. (1993) pointed out it has tended to neglect the Continental version of the debate, including such names as Heidegger and Gadamer, especially with respect to the topic of fostering practical reasoning.

173 “Current attitudes toward foundationalism, as they have been since Descartes, are sharply divided. The minoritarian conviction (Chisholm, Apel, Habermas, Haack, Swinburne, and others) that some version of foundationalism is or is at least potentially viable is outweighed by the majoritarian belief that in the debate since Descartes, foundationalism has died a natural death and cannot be revived” (Rockmore, 2004, p.56).
since Descartes.\textsuperscript{174} "If I had to sum up this understanding in a single formula, it would be that knowledge is to be seen as correct representation of an independent reality. In its original form it saw knowledge as the inner depiction of an outer reality" (p.466)\textsuperscript{175}. It is this more restricted focus that I wish to take notice of when discussing a key notion of language in science education.

Secondly, it acknowledges that there has occurred an "interpretive turn" (Hiley, \textit{et al.}, 1991) in the natural and social sciences, and in the understanding of language—though granted, still subject to much controversy—that seeks to move "beyond objectivism and relativism" according to Bernstein (1983), exemplified by authors such as Rorty and Taylor (in philosophy), Gadamer (in language theory) and Kuhn and Hesse (in the philosophy of science). Such a move can be considered a shift in the philosophical emphasis entirely "from epistemology to hermeneutics", as both Rorty (1979, ch.7) and Gadamer (1975, p.235)\textsuperscript{176} have argued; certainly it can be admitted the relation between

\textsuperscript{174} Rorty, of course, also surfaces representation, but he explicitly ties it to philosophy as a \textit{profession} whose role as a foundational discipline (with its "theory of knowledge" being essentially a "general theory of representation") was to adjudicate all cultural knowledge claims, eventually including scientific ones. His view is comparable to Taylor's: "To know is to represent accurately what is outside the mind; so to understand the possibility and the nature of knowledge is to understand the way in which the mind is able to construct such representation" (p.3).

\textsuperscript{175} Taylor links the success of "knowledge as correct representation" standpoint with two factors: its link with the rise of mechanistic science in the 17\textsuperscript{th} century, whose mechanized world view overthrew the Aristotelean one with its notion of "knowledge as participation" ("being informed by the same \textit{eidous}, the mind participated in the being of the known object, rather than simply depicting it", p.467); the influence of Cartesian philosophy that insisted a new reliable "method" was required that could guarantee \textit{certainty} of the representation. Yet this method entailed, unlike in philosophical antiquity, the reflective and critical cast of individual \textit{mind} performing a subjectivist inward turn. Note as well Rorty for a similar view (1979, p.248).

\textsuperscript{176} He comes at the epistemological issue from the problems created by the attempted objectivism of the historical school and the nature of \textit{historical consciousness}, notably Dilthey: "The problem of epistemology acquires a new urgency through the historical sciences" (p.216); He chides Dilthey for his scientific attempt at making historical studies an "objective science", although he rightfully credits him with opposing the Neo-Kantian school's return to the "epistemological subject" (p.238). Instead of the restricted focus on the isolated cognitive subject (a philosopher's fiction) he comments how Husserl's idea of the \textit{life-world} (extending Dilthey's "standpoint of life") replaces it: "The concept of \textit{life-world} is the anti-thesis of objectivism" (p.239), a concept he likewise foregrounds. Such a notion harbours its own \textit{ontology} (as a structure embracing the worlds which man has experienced). "But this ontology of the world would still remain something quite different from what the natural sciences could even ideally achieve ... the \textit{life-world} means something else, namely, the whole in which we live as historical creatures ... [it] is always at the same time a communal world that involves being with other people ..." (ibid). Later, in his critique of the Enlightenment's notion of objective, ahistorical reason (or "absolute reason"), he comes very close to Rorty: "The epistemological question must be asked here in a fundamentally different way ... The focus of subjectivity is a distorting mirror. The self-awareness of the individual is only a flickering in the closed circuits of historical life" (p.278).
the two modes of inquiry is contentious (Rockmore, 2004; Westphal, 1999; Hiley et al., 1991), and differing conceptions of language inform both of them.

Furthermore, although there are many similarities in Rorty’s and Gadamer’s position, there exist important differences as well as to the nature and task of epistemology and hermeneutics, which is instructive. For example, while Rorty would agree that Anglo-analytic philosophy of language has slowly come to abandon the notion of language as correct “picture of the world”\(^{177}\) he would disagree with Gadamer’s universalist perspective of philosophical hermeneutics (with its inherent view of language as the *medium* of all understanding). Both agree that hermeneutics is not to be considered a successor to epistemology, rather that it involves an entirely different approach to comprehend the world—indeed Rorty construes it as a kind of “paradigm shift”, one that is holistic, historicist and pragmatic; yet while Rorty makes a sharp distinction between the two but sees them as complementary and mutually supportive (epistemology for “normal discourse” and hermeneutics for “abnormal”), Gadamer would see them as antagonists, hermeneutics as the universal condition of understanding (and hence of *being; Dasein*) and epistemology as a failed *epistéme*-based, historico-philosophical endeavor. Rorty correctly stresses that Gadamer has emphasized *Bildung* as historical enculturation (also “education”) as a proper goal of hermeneutics, as an open project of how understanding can be expanded through interpretation and dialogue, instead of strict “knowledge” possession and obsession of the foundationalist project, but he would not consent that such “understanding” entails *knowledge*; Rorty is clear that “knowledge” is fallible and *constrained* to the “normal discourse” of a particular socio-cultural paradigm (explicitly referencing Kuhn’s ideas)\(^{178}\). Taking such a position on a *standard* of knowledge, it can be argued on the other hand, seems to indicate that Rorty’s perspective

\(^{177}\) “Putnam now agrees with Goodman and Wittgenstein: to think of language as a picture of the world—a set of representations which philosophy needs to exhibit as standing in some sort of nonintentional relation to what they represent—is *not* useful in explaining how language is learned or understood” (1979, p.295; original italics).

\(^{178}\) Hence his view and complaint that one can distinguish between “systematizers” (those engrossed in normal discourse) and “edifying” philosophers (anti-foundationalists like Dewey, hermeneutic thinkers like Heidegger, Gadamer, who disrupt it) within the tradition—the latter whose status as ‘true’ philosophers is often questioned by academic professionals.

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still entails (at least implicitly) a commitment to the epistemic assumptions of Cartesian foundationalism.\textsuperscript{179}

There is certainly more that can be surveyed here in the debate about the shift “from epistemology to hermeneutics”. Several very important questions exist that still need addressing, such as, if the common division between \textit{explanation} and \textit{understanding} is abandoned—which has long been accepted as \textit{the} major difference between the natural and social sciences (Mason, 2003)—and “interpretation” comes to characterize all human inquiry, does or should a ‘contrast class’ exist in opposition to it? Theroeto, how can or should one demarcate the lines between the humanities and the different sciences? Moreover, how does one adjudicate between better and worse interpretations? Is hermeneutics\textsuperscript{180} really an alternative paradigm to epistemology (as Gadamer insists), or another albeit expanded and extraordinary version of epistemology itself, just not of the classical foundationalist sort (as Rockmore (2004) and Westphal (1999) contend)?\textsuperscript{181}

There are fundamental issues and concerns identified here that a \textit{philosophy of science}

\textsuperscript{179} Rockmore (2004, p.57) writes that Rorty maintains “a strict but wholly arbitrary distinction between epistemology and hermeneutics in order to equate the failure of foundationalism with a form of skepticism that cannot be alleviated through a hermeneutical turn.” Rockmore insists, rather surprisingly and against Rorty’s explicit views to the contrary, that Rorty in effect still holds to Cartesian foundationalism (which reflects an underlying Platonism), because of his stance that interpretation of itself cannot yield “knowledge” of the kind specified in the long-standing foundationalist task. Thus Rockmore charges that Rorty still clings to a \textit{standard of knowledge} that he admits cannot be met. Rorty freely concludes that one can no longer hope to bring the mind in contact with the real and that \textit{interpretation} must be the alternative, he just denies that this will lead to knowledge in the conventional sense. Alternatively, Rockmore argues that “the main strategy for knowledge is, and always has been, interpretation” (p.57), which should not be regarded as tantamount to skepticism.

\textsuperscript{180} I do not mean to imply this field of study is monolithic, and commentators commonly distinguish between “right wing” (Gadamer) and “left-wing” (Derrida) factions, but such a categorization is overly simplified. Those involved with educational studies—I cite here Gallagher’s (1992) \textit{Hermeneutics and Education}—distinguish four separate schools of thought: conservative (Dilthey; Hirsch), moderate (Gadamer; Ricoeur), radical (Derrida; Foucault) and critical (Habermas; Apel).

\textsuperscript{181} Rockmore maintains that the shift leads to a \textit{redefinition} of epistemology, from “knowing the way the mind-independent world is” to “the interpretation of experience” which is justified by the standards in use in a given cognitive domain. In this reformulation “then epistemology as hermeneutics presents itself as a viable successor to the traditional view of epistemology—indeed as the most likely approach at the start of the new century” (p.11). Westphal criticizes Rorty for failing to distinguish between classical epistemology and hermeneutics seen as a generic epistemological task, hence, to differentiate the replacement of only \textit{one type} (foundationalism): “\textit{hermeneutics is epistemology}, generically construed ... it belongs to the same genus precisely because like them it is a meta-theory about how we should understand the cognitive claims of common sense, of natural and social sciences, and even metaphysics and theology” (p.416; original italics).
education would also need to consider and evaluate, which have necessarily arisen because of the “interpretive turn”\(^{182}\) but which cannot be taken up in this Thesis.

Before examining the contrasting views of language offered by Dewey and Gadamer and what this implies for science education, a brief comparison of Egan with Gadamer may be called for, since Egan has occupied such a central place in this Thesis. Such a comparison will bring to light selected limitations to his metatheory. Some similarities immediately come to mind: both start with the question of meaning and the chief role this must play for understanding (it also performs as learning outcome); thereto, secondly, both have made “understanding” a central concern and the main plank in their philosophy; thirdly, both accept the historicity of language and the fact that this conditions human experience, learning and knowing. Consider as well the obvious similarity between Gadamer’s definition of hermeneutics and Egan’s purpose for education, for I had previously quoted him as stating (see full quote p.108):

We can easily forget that learning symbols in which knowledge is encoded is no guarantee at all of knowing. ... The primary trick in bringing knowledge to life from the codes in which we store it is through the emotions that gave it life in the first place in some other mind. Knowledge, again, is part of living human tissue; books and libraries contain only desiccated codes. The business of education is enabling new minds to bring old knowledge to new life and meaning (Egan, 2005b, pp. 96-7; my italics).

Whereas Gadamer writes:

The best definition for hermeneutics: to let what is alienated by the character of the written word or by the character of being distantiated by cultural or historical distances speak again. This is hermeneutics: to let what seems to be far and alienated speak again (1980; quoted in Bernstein (1983), p.250, footnote 36).

In so far as hermeneutics can be considered an educational task (and Gadamer certainly allows for this possibility) both thinkers’ perspectives intersect. As for historicity, while Egan’s metatheory is premised upon the recapitulation of cultural-linguistic stages as evolved over time in human anthropology it fails to acknowledge Gadamer’s insight and stated principle of “effective-historical consciousness” or otherwise called “History of Effect” (p.299; Wirkungsgeschichtliches Bewuβtsein). This

\(^{182}\) And which has been debated to some extent already in the book collection bearing the same name, The Interpretive Turn, by Hiley et al. (1991).
principle admits that we are inescapably in a “temporal distance” in relation to the past which we cannot overcome; rather as historically-situated social beings we cannot avoid thinking within and out from a given historico-cultural tradition, whose perspective is itself transient and changing and which effects our very being and perception of past and current events, usually in unconscious ways (a major source of our prejudices). Gadamer puts it nicely: “In fact history does not belong to us; we belong to it” (p. 278). In other words, such a condition of our existence cannot allow for any sort of true historical objectivity, and I think it is fair to interpret that Egan’s recapitulation thesis assumes some sort of cultural-linguistic objectivism. One could argue this rejoinder can put into question the “truth value” of the entire metatheory; alternatively, it doesn’t necessarily follow that it is wrong, only that our current “best evidence” (according to present historico-cultural and anthropological understanding, so Egan would argue) speaks in its favour, but that it nonetheless remains fallible (in essence Egan offers a kind of “inference to the best explanation” argument). I don’t think this detracts from its current merit as an educational metatheory. What does detract is (as mentioned last chapter), that a criterion is missing for judging the content knowledge (CK) of science curricular material (esp. textbooks), commonly taken as ahistorical unchanging, objective fact—in line with the typical Enlightenment conception of knowledge objectivism.

Linked to the previous objection one could also make the argument that Egan remains in the orbit of Enlightenment thought in so far as he exhibits those aspects of the philosophical and psychological tradition which seek to fashion the view of the child according to developmental stages that are presumed to be known in advance and can be formulated by theory (eg. whereas Dewey would look to psychology, science education had first looked to Piaget and later to cognitive science, Egan looks to Vygotskian tools developed socio-culturally). It should be noted that hermeneutics takes an entirely different view and does not specify any sort of conception or image of the developing child, instead it takes its lead from Heidegger’s existential notion of persons as “being” (Dasein) which are “thrown-into-the-world.” From this ontological standpoint they reach out and search for meaning and understanding, one which they can only achieve through the “hermeneutic circle of interpretation” as concerned and communal “language” beings. This is in effect an ontological shift away from epistemology, and one could
argue that here, too, Egan remains part of the Western epistemological tradition—at least in so far as one can presume “to know” when and what stages the child will/must pass through and that this can specified as an educational program of development. (This is indicated as well by the fact that Egan talks of “mind” and not “being” of the learner). The advantage such an ontological perspective offers is that it provides insight and a mechanism for how individual learners proceed to learn anything and actually “come to understand.” The one serious disadvantage is that it does not afford the educator a framework for structuring curriculum according to the age-developmental phases of the growing child, allowing for decision-making about “when” and “why” to teach—only the “how to learn”. This should not surprise as hermeneutics is not meant to function as an educational metatheory exclusively, on the contrary as now seems clear, “only” for clarifying the learning process—but as such I submit it provides more powerful ideas for the educator that the constructivist school.

The late philosopher and physicist Martin Eger (1993, pp. 11-19) has provided an astute exposition of this “ontological turn” for science educational purposes, especially with respect to students trying to interpret the language of a science text.\textsuperscript{183} He explicates Gadamer’s notion of the “fusion of horizons” (of meaning) that takes place between the text and the learner (the language horizon of the text and of the student’s language horizon/ perspective, or life-world).\textsuperscript{184} His papers are referenced in subsequent sections.

\textsuperscript{183} “To interpret ... is to ‘enter’ the hermeneutic circle, to project, and to remain thus in motion between the text (or text-equivalent) and the projected fore-meanings. Therefore, a fundamental mode of human being is precisely being in this circle in which the mind is not with itself but is drawn by its own projections to that which it attempts to understand. The reason for describing this as a state or mode of being, rather than simply as an activity among other(s) ... is precisely to identify this mode as ‘primordial!’—prior to all constructions—one without which the human qua human, cannot be understood” (p. 12; original italics).

\textsuperscript{184} “Meaning arises in the interpretation itself. The subject/object cut does not lie between the interpreter on the one side and the text with its meaning on the other (objectivism). Neither does it lie between the text alone on the one side and the meaning inside the interpreter’s mind on the other (subjectivism). As a fixed boundary, the cut is just not there; meaning is not disjoint either from the text or from the interpreter. Rather, a ‘bare’ text is to be thought of as an ontological core, around which potential meanings hover, so to speak, in a space of all possible meanings” (ibid).
5.2. *PoSE Case Study: Science Education, Dewey, Gadamer and Language*

The next sections explore the role and *nature of language* in science education with the specific focus of contrasting the differing perspectives on language as found in two seminal 20th century thinkers, John Dewey and Hans-Georg Gadamer. The broad influence of Dewey's ideas on science education is generally acknowledged (Fensham, 2004; DeBoer, 1991), but as will be argued here, the linguistic assumptions behind his progressivist educational philosophy remain largely unexplored and problematic while they continue at the same time to resonate and detrimentally affect science learning. What is suggested is that these assumptions should be made explicit for science educators while at the same time providing for the exposure to a different conception of language. I will maintain such an alternative can be found in the *philosophical hermeneutics* of Gadamer (1976; 1960), one which embeds instead the well-known dialogical component of language within its *ontological-historical dimensions*, one which stresses that all understanding is essentially *interpretation*, and which sees learning itself as an interpretive event within the "hermeneutic circle" of understanding (Bontekoe, 1996).

Although such ideas may sound radically new and even obscure to most science educators, they actually constitute part of a world-wide scholarly conversation that has taken place for over 25 years pondering the nature of several different domains: language (Medina, 2005); education (Gallagher, 1992; Eger, 1992); science (Ihde, 1998; Heelan, 1991; Hesse, 1980) and philosophy (Hiley *et al.*, 1991; Taylor, 1987; Bernstein, 1983; Rorty, 1979). This overall discussion has come to deliberate upon and value the significance of Gadamer and hermeneutics for these diverse fields. I believe science educators can directly profit from an exposure to that on-going and cross-disciplinary discourse, and this analysis serves the further purpose of illustrating another important role that "philosophy of science education" can fulfill, namely the *critical appraisal of language philosophies as related to science teaching and learning*.

In what follows, I begin by reviewing Dewey's legacy in science education along with some past and current critiques of 'traditional' science education, pointing out that these critiques, too, carry out an understanding of language that is akin to Dewey's. Next, in the fourth and fifth sub-sections, I detail the linguistic assumptions and shortcomings of Dewey's progressivism. In the sixth and seventh sub-sections, the
Gadamerian alternative to Dewey’s ‘progressive linguistics’ is introduced and I detail some of the work in science education that has already begun along hermeneutic lines. What is suggested is a truly progressive understanding of science education that breaks with ‘progressive linguistics.’ (This new progressivism can be called ‘more Deweyan than Dewey’).

As an important preliminary comment it can be admitted at the outset that Dewey in his many books had not completely clarified his views on language, let alone develop what can be considered a full blown “theory of language.” Yet I believe if one carefully canvasses his works certain assumptions and standpoints can be gleaned from them and articulated. There are some authors who may disagree with the analysis here undertaken and the views expressed, and may suppose instead that his ultimate view on language had been presented in his last book (which he co-wrote with Bentley), entitled Knowing and the Known (1949), although I do not share this opinion. While I acknowledge that he does appear to indicate a conception of language as dialogic, or language-in-use, or at least it can be said he seemed to have moved more in this direction later in life—as to what that could mean—this may not have been his exclusive understanding, nor may the later meaning have been the dominant one in most of his previous works. In any event, his other writings indicate a notion of language as will be here indicated—at minimum, he may not have been consistent in his views.

5.3. The Deweyan Legacy in Science Education

In 1916, John Dewey offered a critique of science education that, it can be admitted, still rings considerably true today. In his widely read and still fashionable book Democracy and Education, he wrote the following about science students:

"The necessary consequence is an isolation of science from significant experience. The pupil learns symbols without the key to their meaning. He acquires a technical body of information without ability to trace its connections with the objects and operations with which he is familiar—often he acquires simply a peculiar vocabulary (1916, 220)."

Dewey correctly noted the inability of many science students of his day to translate their classroom learning into what he called “experience” (Dewey, 1938). And reading
Dewey’s words today, we are reminded that the status of critique aimed at science education has changed surprisingly little in the last ninety years. Many of Dewey’s observations on science education could well be contemporary. It is still the case that science education (certainly in physics and chemistry education), is too often plagued by abstract symbolic and rote memory learning (whether in regard to the text and vocabulary employed, or through use of algorithmic problem-solving), rather than meaningful engagement and deeper conceptual understanding (Roberts and Oestman, 1998; Nahkleh, 1992; Mestre, 1991). Science instruction and curricula world-wide (which, sadly, have changed little over many decades, irrespective of several reform “waves”; Osborne and Dillon, 2008; Wallace and Louden, 1998; Van den Akker, 1998) are still characterized, certainly at the upper levels, by the restricted, specialized focus on the mastery of decontextualized and ahistorical ‘technical’ knowledge (Lederman, 1998). Aikenhead (1997) has referred to this ongoing and domineering goal of science education (carrying its own defining “science literacy” preconception) as “technical pre-professional training” (TPT)—which only serves, at best, the small minority of students aiming at science-based careers.  

Most importantly, the language employed in classrooms is still dominated by the “transmission” mode instead of an “interpretive” one (Roth et al., 1997; Sutton, 1996; Mestre, 1991; Lemke, 1990), which in-itself belies a “positivist” view of knowledge—an assumed objectivist epistemology. This transmission model, moreover, is reinforced by the teacher’s overt reliance on textbooks (and their language) which drives both “what is taught and how it is taught” (Stinner, 1995, p.275)—no doubt a major factor in Dewey’s complaint about students’ acquiring only “technical knowledge” and “peculiar vocabulary”. And thus, science education is often not progressive in the Deweyan sense of progressivism. Science education, looking back in time from our vantage, has seemed distinctly unable, either by lack of effort or by lack of disciplinary werewithal, to employ the tenants of progressivism as Dewey laid them out.

From the words of Dewey quoted above, I would like to underscore a few: “vocabulary,” “symbols,” “isolation,” “experience” and “meaning.” While these words

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185 Such a confining preoccupation (learning of science), nonetheless, has consistently failed to develop in students, regardless of their career aims, a proper scientific mind and understanding about science (the development and nature of its concepts, theories and social practices), as many researchers have discussed at length (Lederman, 2007; Jenkins, 2000; Millar and Osborne, 1998; Yager, 1996; Matthews, 1994; Kelly et al., 1993; Bauer, 1992; Duschl, 1990).
have no intrinsic bearing on science education, it can be noted that they are loaded with assumptions about the way that language gets used in science education to impede deep learning on the part of the student. So if ‘vocabulary’ and ‘symbols’ stay at the level of abstraction, if they stay ‘isolated’ in the mind of the student, then the student will not be able to gain ‘experience’ of the scientific notion under study, nor will he or she be able to make ‘meaning’ of it. What I want to underscore here is that language is intimately connected to the progressive critique of traditionalist science education. For Dewey, there is a direct correlation between the way that language gets used during the process of learning science, and the way students do or do not make meaning of the science under study. Dewey’s observations, then, may or may not be so contemporary, depending upon whether recent critiques do or do not share the linguistic assumptions of Dewey’s progressive educational project.

At first glance there would certainly seem to be considerable merit in his critiques of traditional science pedagogy, even sustained as they were by his linguistic assumptions (to be examined below in section four). It is no doubt because of these sorts of insights that Dewey has exerted a sizeable influence on science curricular change, more so in North America during the pre-World War II era. His main charges being: i) that the structure of a discipline was a poor place to begin to learn a subject (whereas it should be properly aimed for at the end of studies); ii) that much classroom knowledge remained “inert” and useless in students’ minds; and iii) that science education should be about connecting curriculum to students’ personal meaning while enabling them to acquire the kind of scientific reasoning skills ostensibly employed by scientists themselves (Dewey, 1945; 1938; 1916). Indeed, it is not only because of his insightful criticisms but especially his new conceptualization of the nature of schooling (as enculturation into democratic thinking and living) linked to the central role of science education within it, that he can still be seen, rightly or wrongly, as the only major philosopher of education whose ideas have significantly shaped aspects of science pedagogy not only in the past but which still hold sway in some fashion in the present, in the English-speaking world (Kruckeberg, 2006; Fenshaw, 2004; Wong et al., 2002; Shamos, 1995).

Although his contributions to science education reform are numerous his principal influence came in two separate reform “waves”, the first during his lifetime, in the so-
called “progressive era” (roughly 1917 to 1957) of American education, and the second
time (though rather less directly) with the “new progressivism” and “science literacy”
emphasis of the 1970s and 80s, including the Science-Technology-Society (STS) reform
movement (DeBoer, 1991). In both of these instances his legacy was felt in those
curriculum designs which not only called for, but actually managed a partial shift in the
key goals of science education. The shift of emphasis was away from one focused
predominately on mastery of science subject disciplines and textbook-based instruction
(the customary “knowledge” goal) to instead the new double emphasis placed upon
mastery of the alleged “science method” (as a problem-solving, socio-linguistic-based
tool), as well as what has come to be known as “science for social relevance” (Bybee and
DeBoer, 1994). This included a stress on more “student-centered instruction”, which
meant for Dewey that the subject material should be chosen from the pupil’s immediate
social environment and experience, that it should also exhibit some kind of application,
and that practical (not just numerical) problem-solving would be involved within this
personal field. Such innovative ideas for his time, needless to say, have today become
part of the common conversational landscape and contributed to positive changes on the
part of science teachers’ attitudes and conceptions of science teaching and learning.

And yet these shifts did not go unchallenged by more traditional-minded science
educators, not even in his time (who continued to lay stress instead on knowledge
attained through science discipline structures, as many still do today). And the “social
relevance” curricular theme—certainly reinterpreted and expanded since then (DeBoer,
1991)—has not been universally endorsed (and where endorsed only to limited degrees),
being plagued by various kinds of substantive interpretive, value-based and practical
problems. In particular, under the guise of “social context” in the STS movement,
considerable disputes erupted during the so-called “curricular wars” of the 1980s
surrounding the question of what the fundamental goals of science education should be,
including its own self-conception as a discipline—whether it was to be (putting the issue
in simplified terms) more concerned with discipline-centered knowledge (as ends) or
instead “knowledge-in-use” (as means) for social purposes (Bybee & DeBoer, 1994, pp.
378-380; Good et al., 1985; Yager, 1984).\footnote{Dewey’s preference was clear: “We may reject knowledge of the past as the end of education and thereby only emphasize its importance as a means” (1938, p.23, original italics).} Unfortunately, important aspects of these disputes remain unresolved to this day within the worldwide science education community, especially with respect to the contending conceptions of “science literacy” (for example, how and if it should be tied to citizenship) as a defining goal and hence what the suitable orientation of the curriculum should be (Roberts, 2007; Zeidler et al., 2005; DeBoer, 2000; Roberts & Oestman, 1998; Shamos, 1995; AAAS, 1993).

It was certainly Dewey’s unique and particular stress that a supposed “method” was to be taken as both means and ends, as a means to how knowledge is acquired, but also as a goal of instruction, for he maintained the essence and power of science lay moreso in its method of inquiry than as an accumulated body of ‘technical’ knowledge (Bybee & DeBoer, 1994, p. 371; Dewey, 1945). And because he believed that such a method could be cultivated in students as an attitude, as a generic way of thinking and problem-solving (through the correct use of language as a representational and social tool)—what he termed “scientific habits of mind”—it could be applied to any subject matter, and therefore, he assumed, it would help them solve real-life problems and prepare for democratic citizenship in the emerging, ever-changing industrialized society of his day.

His sense of science education then was also intimately tied to his reformulated purpose for schools, now well-known, namely, “to ensure that students secured knowledge which would assist them in coping with the problems they faced as participants in society”. Hence the paramount stress on the utility of knowledge, “how things worked and how to do things” instead of “knowledge about things” (Briscoe, 1990, p. 21). In this perspective, science education was to play a central and leading role in such a revised curriculum, necessarily forcing a kind of subordinate status on the other school subjects. As could be expected, such a prioritizing of subjects and goals naturally lead to resistance on the part of science and especially non-science teachers. Moreover, the chief focus on the utility of knowledge and schooling for the predominant purpose of fostering “critical citizenship”—especially for those topical reform movements which have taken this view entirely on board for science education, like STS (Yager, 1996;
Solomon & Aikenhead, 1994) and others aligned with it ("socio-political activism"; Hodson, 2003; Roth & Desautel, 2002)—harbours considerable problems in its own right. Namely, that it tends to diminish knowledge-in-itself as an intellectual pursuit—also the aesthetic, creative side of science—as well as other values of science education, such as for personal self-development and advancing cultural literacy, among others (DeBoer, 2000).

Be that as it may, it is not our immediate purpose to critically appraise these influential ideas of Dewey here (which continue to be pursued in various aforementioned guises), others have already done so: especially concerning those ideas feeding contemporary progressivist notions which still interpret and seek to instrumentalize education as a prevailing socializing project (Egan, 2002; Jenkins, 1997; Apple, 1992; Nyberg & Egan, 1981); above all, the judicious reappraisal of his various views on "science method" taken as "thinking habits", also "process" and experimental inquiry\(^{187}\)—whether related to the questionable legitimacy of his views on scientific methodology (as a type of hypothetico-deductive reasoning, now seen in light of competing views in recent philosophy of science; Duschl, 1994; Suppe, 1977)—or especially how his views on "logical attitudes" and scientific "habits of mind" bear upon current discussions on "critical thinking", which have now come to heavily criticize his original notion of generic and transferable thinking skills (Bailin, 2002; Hodson, 1996; Kuhn, 1993). Although the several factors listed can help account for the stalling of the Deweyan project over time (each contributing in its own way), our immediate focus is on his conception of language. It is his linguistic conception, it will be argued, that is at the crux of what has proven to be most unworkable for what might otherwise have been a more successful program of progressive science education.

\(^{187}\) Which has helped shape, along with Schwab (1962), the popular "science as inquiry" approach in science education, and remains very active today (see the NSTA supported book by Llewellyn, 2005).
5.4. John Dewey’s Linguistic Assumptions

To truly understand the progressivism of Dewey, then, one must understand his overall orientation toward language itself. And to be clear about this orientation, one should note at least four tenets of what I am calling Dewey’s ‘progressivist linguistics’, four assumptions that Dewey makes about language. First, language is *representational*. Language symbolizes ideas and things, and in doing so, allows humans to communicate without much unnecessary toil. If people didn’t have the use of language, they would need to go to great lengths, using gestures or even replicating the thing to be represented, in order to communicate. But since language is available to *reflect reality*, we can communicate without much effort. Of course, this representational aspect of language comes with one primary need: that language be used to represent *well*. Since language is a mirroring of the world, we must be careful to clean the mirror and make it shine. The better that language reflects, the better language does its job.

In *How we Think*, Dewey describes the role of linguistic symbols in the thinking process as follows:

[Symbols] are symbols only by virtue of what they suggest and represent, i.e. meanings. They stand for these meanings to any individual only when he has had experience of some situation to which these meanings are actually relevant. Words can detach and preserve a meaning only when the meaning has been first involved in our own direct intercourse with the thing. To attempt to give a meaning through a word alone without any dealings with a thing is to deprive the word of intelligible signification; against this attempt, a tendency only too prevalent in education, reformers have protested (1910, 176).

*Language is a symbol system that, on its own, unforced by human will, does not lend itself to meaning*. Language remains in the form of the uninterpreted symbol if not connected to experience. Language remains sedentary as a symbol system until memory and experience are brought to bear through the use of language. Unless people use language for thinking, it will remain ‘only’ a symbol.

Second, language is *instrumental*. Language helps us to do two things, to think and to communicate. To understand, first, how language helps us to think, we can quote Dewey:
To say that language is necessary for thinking is to say that signs are necessary. Thought deals not with bare things, but with their meanings, their suggestions; and meanings, in order to be apprehended, must be embodied in sensible and particular existences. Without meaning, things are nothing but blind stimuli or chance sources of pleasure and pain... (1910, 171).

If language didn’t exist, then a person could only think for him or herself if that person could address every thought by interacting with its concrete existence. This would be such a cumbersome situation that the thinker would never get much thinking done. But the thinker can, instead, use language as a short-cut to thinking, a short-cut that need not deal with concrete existence. Language is like a road map of a city. It allows us to deal in a conceptual way with all those roads we haven’t been on. Language, in other words, is a tool for thinking. It is a good, versatile, light (in fact weightless), tool. Language is also a good tool for sending meaning from one person to another. When language sends the thought of one person to the waiting mind of another, language has helped one person to understand another. Language is a tool not unlike a conduit; its structure allows transfer from one thinker to another.

Dewey’s often-cited description of language as the “tool of tools” once again brings home this instrumental understanding of language:

But at every point appliances and application, utensils and uses, are bound up with directions, suggestions and records made possible by speech; what has been said about the role of tools is subject to a condition supplied by language, the tool of tools (1981, 134).

Third, language can be separated into its intersubjective and cognitive elements. Dewey maintains that language allows individuals to be in contact with one another, and that it also helps us to think. For Dewey, language is most often used for the former rather than the latter. People’s communication differs from thinking insofar as communication does not trouble the nature of what is being communicated, whereas thinking always troubles the nature of the symbol into meaning-making. It is easier to communicate than it is to think, and so people most often settle for communication. Dewey notes,
The primary motive for language is to influence (through the expression of desire, emotion, and thought) the activity of others; its secondary use is to enter into more intimate sociable relations with them; its employment as a conscious vehicle of thought and knowledge is a tertiary, and relatively late, formation (1910, 179).

So language can influence, it can establish relations, or it can embrace thought. The first of these two are oriented toward intersubjectivity per se, while the last has a cognitive aspect as well. The use of language for relation is more ubiquitous than the use of language for thinking because the former’s origins are so ancient. That language’s “primary motive” is to establish relation intimates a linguistic anthropological prejudice that follows directly from Dewey’s Darwinian understanding of primate development and Spencerian view of evolution (Egan, 2002). Before human beings even acquired language, they were social beings. The tool of language came later, and it was used first of all to foster sociability. Only later, apparently, did it take on a more cognitive function.

This Deweyan distinction—between influencing an other, entering social relations with an other, and transmission of information to an other—actually fine-tunes the aforementioned instrumental and symbolic descriptions of language. As an instrument, as the “tool of tools,” language serves as a means to two possible ends. On the one hand, language may be used to nudge, or poke, or move another person. It may be used to establish bonds. On the other, it may be used as a vehicle (a conduit, as stated previously) for moving ideas, thoughts, and meaning from one person to the next. So the tool of language may be a tool pure and simple, or it may be a tool with meaning inside. It may be a hammer, or it may be a Trojan horse. Both are tools, but one has contents that are bound to inform and surprise. As a symbol, too, language may be primarily intersubjective, or it may be more informative. Most linguistic symbols, at least under this Deweyan description, have meanings that enable humans to convey social demands and social desires to one another. Yes, linguistic symbols stand for human meanings and are therefore more complex than rudimentary gestures, nevertheless, most of them lead to relations rather than thinking itself. It is only at the more self-aware, contemplative end
of the spectrum of human interaction where symbols become thick with rational intentions.

Fourth, language is on a different ontological plane than other states of being. This last Deweyan commitment to language is best understood as the common denominator of the first three assumptions mentioned above. When language is symbolic, when it is instrumental, and when it serves the higher purposes of interaction and thinking, it has such attributes and functions because it is fundamentally different than non-linguistic life. Language is different from other sorts of experience. It symbolizes things without being those things. It is used like a tool toward certain ends without being a part of those ends. It fosters human interaction but it is not human interaction per se. It is used to promote thinking without being the thinking that it promotes.\footnote{Dewey writes, "...while language is not thought it is necessary for thinking..." (1910, p. 170).} This profound difference between language and other aspects of life is clearly demonstrated by the secondary roles that Dewey assigns to language. Language, under its Deweyan description, brings on, or sometimes stalls, but is certainly not the same as, human experience.

Dewey is certainly not unusual with regard to this presumed ontological difference. John Stewart, who calls this perspective of ontological difference a "two worlds" commitment, has noted the following:

...the two worlds claim is most basic. As reviews of the history of linguistics demonstrate in detail, this claim embodies the ontology first established in Platonic and Aristotelian formulations of the nature of language. The basic distinction between linguistic and non-linguistic worlds was articulated explicitly in the influential Aristotelian formula that Heidegger cited: "Spoken words are the symbols of mental experience and written words are the symbols of spoken words." This became the medieval claim linking aliqua and aliqua, which was developed into John Locke's claim that words are "signs" that signify "ideas," and the connection in Wittgenstein's Tractatus Logico-Philosophicus between "propositions" and the "objects of thought" that they "picture." (Stewart, 1996, 16).

For the purposes of this chapter, there is no need to follow up on these historical echoes of language's ontological difference other than to say that Dewey was in good
company. As will be pointed out later, though, by joining this longstanding commitment to two worlds, Dewey derails his own progressive project. The two world commitment is both central to Dewey’s other linguistic assumptions, and central to the unsustainability of progressive education in general, and progressive science education in particular.

It should be pointed out, though, that the linguistic company that Dewey keeps locates him primarily within one of two great semantic traditions in the history of philosophy, that the philosopher Charles Taylor has termed designative. This major tradition can be contrasted with the alternative expressive tradition, which he traces back to Herder and Humboldt in German Romanticism (early 19th century), and has continued in time to be further elaborated by authors such as Husserl, Heidegger and Gadamer, and which is linked to the “dialogic perspectives” of language by such diverse modern thinkers as Wittgenstein, Bakhtin, Foucault, Habermas and Rorty (Medina, 2005, pp. 39-46). As will be elucidated below, these two traditions, broadly conceived, mark out a fundamental difference in the conception of what language is and does, seen either primarily as “symbol and tool” and hence as contrasted with real “lived experience”, or

190 It could be argued that Dewey in his last work (1949)—where he seeks to explicate his position at overcoming the dualism of the Cartesian subject-object epistemology which he saw behind Western thought in general—that he includes a view of language-in-use largely inconsistent with the “tool” notion and “two world commitment” as I have here so far described and analyzed. It is true that while Dewey takes ‘naming’ and the ‘named’ (or “designation”) as a key inter-connected behavioural activity—one he calls “transaction” and which he states in effect is a “linguistic activity” (p.144)—this does not exclude a two world commitment of understanding per se as to what language in essence is, although on the surface it may appear so. Indeed, linguistic activity might well connect naming and the named. Still, the fact that language functions as a tool during such connecting suggests nevertheless that language is of a different world than both the naming and the named. Language itself remains ephemeral while behavioral activity is of the world of naming and the named that Dewey attempts to connect. Dewey does object to the use of ‘name’ as a tool, but this view is directly linked to his objection of such a notion as strictly related to an objectivist epistemology—where “word” is considered a “thing”, in fact a “third thing” belonging to an individual subjectivist mind (see p.146). It does not, as far as we can judge, dismiss the idea of language as an inter-subjective tool (as we have argued) brought about through a transaction of naming and language use in community. Hence, his entire emphasis on naming as a “behavioral process itself in action, with the understanding … that many forms of behaviour … operate as instrumental to other behavioral processes ...” (ibid.).
191 “The designative tradition depicted language as a crucial instrument of knowledge, a very important representational tool, but nothing more than a tool. By contrast, the expressive tradition ... emphasized that language has more than instrumental value: it has constitutive value, for it constitutes who we are, how we think and how we live. On the Romantic view ... language, far from being a mere tool that we use, is part of who we are: it defines our humanity and sets the parameters of the life we lead” (Medina, 2005, p.41; original italics).
instead viewed as the medium of the “life-world” experience of human understanding itself.

5.5. Dewey’s Linguistic Progressivism

Given the above synopsis of Dewey’s linguistic assumptions, I will now offer an analysis on how these linguistic assumptions bear on progressive pedagogy. Using the four-part metric offered above, it is possible to interpret Dewey’s progressivism in a linguistic way. This interpretation will map Dewey’s linguistic assumptions onto his progressive, educational preferences, as well as onto his biases against traditional education.

Language is Representational

Dewey links the representational nature of language to progressivism by noting that there are three possible aims of education when it comes to representation: to focus on language itself (“pure symbol”), to focus mainly on the object of representation (“pure experience”), to focus both on the object and on language. Certainly, a mere verbalism, or “verbal methods,” are the choices of the traditional methods Dewey rails against (1910, 178). And Dewey is also not interested in the uncontrollable nature of the direct experience. Progressivism opts for the third way, insisting that words and objects go hand-in-hand within educative experience. For Dewey, words and objects are as natural a pair as the map and its city. They must be experienced with each other if the country student is to be educated about the city. This is precisely why Dewey does not abandon education per se in turn for direct experience. For him, the symbol and the thing, together, are a necessity for thinking and learning.

But language can remain at the passive level of symbol when not pushed into thought and meaning: This is well explained by Dewey in the following passage:

The outcome is written large in the history of education. Pupils begin their study of science with texts in which the subject is organized into topics according to the order of the specialist. Technical concepts, with their definitions, are introduced at the outset. Laws are introduced at a very early stage, with at best a few indications of the way in which they were arrived at. The pupils learn a “science” instead of learning the
scientific way of treating the familiar material of ordinary experience (1916, 220).

When language stays at the level of symbol and abstraction, then students (and often teachers) become satisfied with mere "verbalism", with the façade of true thinking and knowing. Such instances of verbalism were ripe in the science classrooms against which Dewey rails, and progressivism, on the contrary, champions experiences that are real experiences rather than simulacra of experiences. Dewey is thus not happy with the pedagogical implications of language's representational life. Progressive education would use language as a symbol system only as a means to another end—that end being an educational experience rather than educational verbalism.

Here one can think of all the books in a well-stacked library. In the library resides language. The traditional educator will give books to his or her students, but the learning will only be 'book learning.' The traditional student will not make personal meaning out of those tenacious, abstract symbols. This traditional student can be contrasted to the progressive student who will experience words as alive and meaningful. For the traditional student, the books remain passive symbols of someone else's authority, while for the progressive student, these same books will come to life and break out of their symbolic constraints.

*Language is an Instrument or a Tool*

This assumption coincides with the communal nature of progressive education. As an instrument for thinking, the word is never mine alone. It has always been initiated by someone else, and I am indebted to that someone else for making the sign useful to me. That the sign allows me to think means that someone else has helped me to think. Language serves to link together people who shared the experience of its use. It creates bonds for those who have used the same words. Language is a communicative endeavor. It facilitates interaction, communion, dialogue, and in fact all the necessary person-to-person interactions that are so necessary to a fruitful reconstruction of democratic habits. Education, like democracy, "...is primarily a mode of associated living, of conjoint communicated experience. The extension in space of the number of individuals who

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participate in an interest so that each has to refer his own action to that of others” (1916, 87). Education, like democracy, uses language for its communal ends.

For Dewey, the tool of language is used poorly in traditional education. It is misused because the traditional educator gives edicts and pronouncements rather than encouraging participation and discussion. The traditional educator does not use words to bring students together, and this happens primarily because the traditional educator considers the autonomous growth of rational minds the most important goal of education. When Dewey rails against traditional education by stating that the ‘funnel’ metaphor of traditionalists must be replaced with the ‘pump’ metaphor of progressivists, he reminds us that traditional education sees students as disparate ‘vessels’ to be filled, one by one. Language, according to Dewey, can serve this purpose. It can act as a conduit for the transmission of meaning from individual to individual. However, if language is used in this way, then it will not fulfill the social aims of progressive education.

Language has Intersubjective and Cognitive Elements.

Dewey’s recognizes in language two elements that roughly parallel the distinction between progressive and traditional education. Language serves to bring people together, and language serves to transfer meaning from one person to another. While progressive education is concerned with the former function of language, that of bringing people together, traditional education is concerned with the latter function, that of transferring meaning from teacher to student. Here is where the two primary goals of progressive pedagogy, the goal of social amelioration and experiential learning, can be seen most starkly as two corollaries of a particular linguistic orientation. For Dewey, the intersubjective role of language is to be lauded because language brings people together for a greater social good. The cognitive role of language, on the other hand, is something to be tolerated, at best, and more preferably eschewed. If enhanced thinking is a goal of education, and certainly progressive education does not shy away from thought itself, then such thinking is better done through experience than through language. While progressive education embraces the social agenda of language, it eschews its cognitive elements by advocating experience over talking.
Once again, traditional education commits a linguistic *faux pas*, embracing the wrong end of the linguistic spectrum. If language functions on a continuum from sheer intersubjectivity, on one hand, to sheer autonomous cognition, on the other, then it is the linguistic mistake of traditional education to emphasize the wrong end of this continuum.

*Language is on a Different Ontological Plane*

The commitment to two worlds, one where language abides and another where ‘real’ experience happens, is, as I intimated earlier, the bedrock of Dewey’s progressive linguistics. It is the common denominator of language as symbolic and social/cognitive tool. This commitment to two worlds is, first of all, a way of describing the difference between something that helps to achieve a goal, and the goal itself. It differentiates between tools and non-tools. Second, this commitment distinguishes between a symbol, on one hand, and the thing such a symbol stands for, on the other. Third, this commitment illustrates the two ends of a linguistic spectrum. On one end, the intersubjective end, language causes something ‘real’ to happen. On the other end, the cognitive end, language causes ‘mere’ thinking (as opposed to ‘real’ doing). Thus the commitment to two worlds helps to establish the various ways in which language falls short of the more serious business of ‘real’ experience.

This bedrock, two-world, understanding of language helps to supply what might be considered the guiding metaphor for progressive education. Progressive education, after all, is an alternative to traditional education. It is an alternative to an older form of education that is presumed to be somewhat *less* than experiential, somewhat less than socially ameliorating. This new alternative is to traditional education what language is to the ‘real’ world. Thus when Dewey describes the “linguistic” methods of traditional education, he invokes a two-world framework that was, and still is, quite a common understanding of language versus ‘real’ life.

*Shortcomings of Progressive Linguistics*

While progressive linguistics provides Dewey with a concrete, linguistic metaphor for the difference between progressivism and traditionalism, it is important to understand that, ultimately, such an understanding of language *undoes* progressivism at
the same time that it provides its bedrock. Dewey’s theory of language paints him into a corner where his only options are to either escape from language more or less completely, or, make the same linguistic blunders that he accuses traditional education of making. This can be explained with further recourse to the linguistic themes elaborated above.

With regard to instrumentalism, it should not be forgotten that it is in the nature of a tool to be used for a purpose, and then to be cast aside. When one uses a hammer, for example, one uses it for the purpose of driving in a nail. When that hammer has served its purpose, and when the nail has been driven, then the hammer is of no more use. It is thus in the nature of a tool that the tool should outlive its usefulness. In this regard, I repeat, it should not be forgotten that Dewey considers language the ‘tool of tools.’ And, indeed, when Dewey’s progressivism is put under close linguistic scrutiny, one finds that the educational use of language is put in the same tenuous position as other tools.

Language itself is a tool that serves other ends, ends that, once achieved, signal that language has served its role and is no longer needed. Language serves as a tool for sociability and language serves as a tool for thinking, but ultimately, language is no longer needed once it has served these ends.

Insofar as education itself should be considered a linguistic endeavor, Dewey’s instrumental understanding of language paints him into a corner. Language, as it appears in curriculum documents, and in the words that are exchanged between students and teachers, is something to be experienced for a while as a means to further ends. The very life of education—its curriculum, its pedagogy, its student interactions—are linguistic practices to be experienced for only as long as necessary in order to master them. After such a time as these linguistic tools have been successfully used, it is time to discard them and get on with the experience for which linguistic interaction prepares one. The school provides linguistic tools to be used and then discarded when they are no longer necessary.

All of this would be fine if progressivism promoted a version of education similar to the one promoted by traditional accounts, a version where education is preparatory to the rest of life. But Dewey in fact promotes just the opposite. Perhaps most famous of Dewey’s criticisms of traditional education is that it is preparatory rather than
participatory. Contrasting his own progressivism with traditional ideas, Dewey states in *Democracy and Education*:

The first contrast is with the idea that education is a process of preparation or getting ready. What is to be prepared for is, of course, the responsibilities and privileges of adult life. Children are not regarded as social members in full and regular standing. They are looked upon as candidates; they are placed on the waiting list (1916, 54).

Dewey is in a tight spot here. He promotes language as the tool of tools. And following the progressive program, education is a venue where this tool of tools is used for community-building and for thinking. But if language is instrumental in this way, then progressive education itself, insofar as it must be an endeavor *in language*, is no less preparatory than traditional education.

Dewey's understanding of the *symbolic role of language* is no less pernicious in undercutting the progressive project. In this regard, it is instructive to look at his symbolic understanding of curriculum. In *The Child and the Curriculum*, Dewey describes curriculum as a map, an ordered set of instructions symbolizing the combined wisdom generated by thinkers of the past. The "map" of curriculum serves to show students the quickest way to negotiate "knowledges" handed down to them.

The map is not a substitute for a personal experience. The map does not take the place of an actual journey. The logically formulated material of a science or branch of learning, of a study, is no substitute for the having of individual experiences. The mathematical formula for a falling body does not take the place of personal contact an immediate individual experience with the falling thing. But the map, a summary, an arranged and orderly view of previous experiences, serves as a guide to future experience... (1901, p. 20).

For Dewey, curriculum serves as symbol for "the having of individual experiences." And this symbolic relationship of curriculum to experience, is none other than, is equivalent to, the symbolic relationship of language to "real" life. Dewey has succinctly stated this equivalence in his influential book *Democracy and Education*.
It has been mentioned, incidentally, that scientific statements, or logical form, implies the use of signs or symbols. The statement applies, of course, to all use of language. But in the vernacular, the mind proceeds directly from the symbol to the thing signified (1916, 222).

Here, in his own description of curriculum-as-linguistic-symbol, Dewey paints himself into the corner of saying something somewhat contradictory about progressive education. While the natural tendency, the vernacular tendency, of language use is to "proceed directly from the symbol to the thing signified," the educational tendency of progressive education is to create curriculum that, while facilitating the transmission of vast amounts of accrued knowledge, requires a symbolic detour on the part of the student, a detour that is neither natural nor of the vernacular. It is once again difficult to see how progressive education succeeds at its own calling to be of experience rather than preparatory to experience—this, because of Dewey's own account of the linguistic/symbolic role of curriculum.

Progressivism is similarly hamstrung by its commitment to language as both intersubjective and cognitive. As previously mentioned, Dewey most appreciates language when it serves as a tool for human interaction. He most appreciates that "the primary motive for language is to influence (through the expression of desire, emotion, and thought) the activity of others" (1910, 179). Following Dewey's philosophical anthropology of language, language's role in thinking and cognitive expression is more of an afterthought, and thus less true to the human condition of sociability. To emphasize, once again, this appreciation for language's social aspects, these words from Experience and Nature are instructive:

The heart of language is not "expression" of something antecedent, much less expression of antecedent thought. It is communication; the establishment of cooperation in an activity in which there are partners, and in which the activity of each is modified and regulated [coordinated] by partnership (1981, 141).

At first glance, this bias of Dewey's against language that it is an "expression of antecedent thought" is in keeping with his bias against traditional education as a practice of transmission rather than growth. But as it turns out, this linguistic bias of Dewey's is also a fair condemnation of progressive education too. If expression of antecedent thought is, as Dewey maintains, a derivative linguistic activity, it is instructive to go back
once again to the linguistic/symbolic role of curriculum. For curriculum, too, no matter how well “psychologized,” is fundamentally a matter of expressing antecedent thought (Dewey, 1901). As Dewey prioritizes the intersubjective elements of language over its cognitive uses, one must wonder if education itself, whether it be progressive or traditional, isn’t being de-prioritized at the same time. On one hand, Dewey explains the educational benefit of using language’s cognitive elements in experiential ways, emphasizing how curriculum should be taken out of its abstract state and psychologized by students. On the other hand, he maintains that language’s expressive, cognitive functions are not at all at the “heart” of language, are not its true orientation. So progressive education, because it must deal with concepts and ideas, with curriculum and symbols, continues, out of necessity, to have dealings with the less admirable elements of language. Thus progressive education, following Dewey’s own account of language, uses the tool of language in the wrong way.

As indicated earlier, the two-world commitment can be considered the bedrock of Dewey’s linguistic metaphors, pitting the progressive education of experience against the traditional education of verbalism. Statements like this, about the tool of language, are to be expected in Dewey’s work:

The emphasis in school upon this particular tool has, however, its dangers—dangers which are not theoretical but exhibited in practice. Why is it, in spite of the fact that teaching by pouring in, learning by a passive absorption, are universally condemned, that they are still so entrenched in practice? That education is not an affair of "telling" and being told, but an active and constructive process, is a principle almost as generally violated in practice as conceded in theory. Is not this deplorable situation due to the fact that the doctrine is itself merely told? It is preached; it is lectured; it is written about (1916, 38).

Suffice it to say, the two-world commitment is no less of a bedrock when it comes the corner into which Dewey paints himself due to his linguistic commitments. In fact, Dewey quite obviously here uses the language side of the two-world metaphor to critique traditional education when progressive education itself can no more do without language than its traditional counterpart. Even as Dewey offers the above criticism, his rhetoric belies his argument: “Is not this deplorable situation due to the fact that the doctrine is
itself merely told?” In what is meant to be a poignant critique of the progressives-gone-verbal, it should not go unnoticed to the reader of Democracy and Education that he or she is, in fact, a reader, and that Dewey himself has just used words to tell us how the doctrine is merely told. This is not to say that Dewey must himself be a stand-in for progressivism, or that when Dewey speaks, progressivism has also made the error of speaking. It is rather to point out the more general difficulty, if not impossibility, of “getting out of language” and into (“real-life”) experience. The two-world commitment supplies an easy metaphor to imply that such a thing can be accomplished, and that it can be accomplished by progressive education. But Dewey’s own conception of the symbolic/linguistic nature of progressive curriculum quickly subverts this easy metaphor.

5.6. Hans-Georg Gadamer on the Nature of Language

To repeat, it is my contention that John Dewey’s project of making science education progressive has been hamstrung by his symbolic, tool-oriented conception of language, an understanding that clings to the two-world commitment that language is on a different ontological plane than other sorts of experience. And thus, the failure of the progressivist project to reform science education, I maintain, can in large part be attributed to a continued adherence to language as tool and symbol, as social but not cognitive, as part of a world that is not altogether ‘real.’ In order to create the conditions for a truly ‘progressive’ science education, it is not enough to follow Dewey’s lead. One must also, paradoxically, break with Dewey. In order to make this break with Dewey and his particular linguistics, one must turn to the language theory of Hans-Georg Gadamer. To illustrate Gadamer’s hermeneutic understanding of language, it is useful to revisit the four linguistic assumptions previously attributed to Dewey, and to offer a Gadamerian alternative to each.

First of all, language is not solely representational. While it is a commonplace assumption in most Western conceptions of language to take language as primarily symbolic or representational, and while Dewey’s conception of language typifies this sort of assumption, Gadamer helps to elucidate language’s other-than-representational qualities. He notes:

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192 For further analysis on the non-representational nature of language see Bingham (2009, pp. 41-63; 2005; 2002).
But the metaphor of a mirror is not fully adequate to the phenomenon of language, for in the last analysis language is not simply a mirror. What we perceive in it is not merely a "reflection" of our own and all being; it is the living out of what it is with us—not only in the concrete interrelationships of work and politics but in all the other relationships and dependencies that comprise our world.

Language, then, is not the finally found anonymous subject of all social-historical processes and action, which presents the whole of its activities as objectivations to our observing gaze; rather, it is by itself the game of interpretation that we all are engaged in every day (1976, 32).

There are at least two parts to the claim that "language is not simply a mirror." The first is that there are many elements of language, indeed, the preponderance of its elements, that, while they certainly contribute to communication, do not symbolize anything. Communication theorist John Stewart explains this as follows:

[In conversation]...interlocutors are as engaged in negotiating their respective identities as they are in making assertions. Questions are at least as important as answers, and pause, stress, rhythm, facial expression, proximity, gesture, movement, and various unmarked features of vocal intonation contribute significantly to conversational outcomes (1996, 23).

While it can't be denied that some part of language is used to denote certain physical and mental concepts, much more of what language does consists in the more intangible negotiation of human ways of being, the "other relationships and dependencies that comprise our world," (1976, 32), that one cannot precisely point to in a physical way, or explain through propositional logic.

Another part to Gadamer's claim is that language is always already in the mode of interpretation even when it might seem to be only or "simply" symbolic. Take a statement like, "I heard a bear just outside the door last night." At first glance, this might seem to be the description of a physical state. It can be taken to be representational. However, such a statement, whether it is encountered in conversation or in text, cannot be taken in its human meaning unless it is subject to interpretation. Such a statement takes its listener or its reader with it. The statement forces into play a chain of hermeneutic dependencies. It brings out presumptions, associations, feelings, deductions, even out-
and-out guesses, as to its meaning and significance. As Gadamer insists, the human subject, upon hearing or reading such a statement, is not at leisure to do just anything with such a statement. He or she must contextualize it, relate to it, fill it with meaning and dependencies. Likewise, the statement’s originator, whether that person be a speaker or a writer, is never in a position to intend such a statement exactly as he or she chooses. The originator must always relinquish interpretive rights to some extent since the statement is as much dependent upon addressee as it is upon addressee. It is in this sense that the statement is in play “in the game of interpretation that we are all engaged in every day” (1976, 32).

A second contrast to Dewey’s linguistic assumptions is Gadamer’s insistence that language is not a tool. To quote Gadamer at length:

Language is by no means simply an instrument, a tool. For it is in the nature of the tool that we master its use, which is to say we take it in hand and lay it aside when it has done its service. That is not the same as when we take the words of language, lying ready in the mouth, and with their use let them sink back into the general store of words over which we dispose. Such an analogy is false because we never find ourselves as consciousness over against the world and, as it were [sic], grasp after a tool of understanding in a wordless condition (1976, 62).

Whereas for Dewey language is the “tool of tools,” for Gadamer the tool analogy neglects the lived debt that human beings always already owe to a linguistically situated consciousness. Once again, one can highlight a couple of aspects of Gadamer’s linguistic critique, this time as it applies to the tool analogy. Words are the possession of everyone rather than the possession of specific individuals. Insofar as words are passed from mouth to mouth, they are changed and inflected in ways that tools can never be. While a tool can be flexible in its applications, its use never actually depends on the aggregation of individuals who have used it in the past. A tool remains the same tool no matter who has used it previously. Language on the other hand has uses that have been historically and socially inflected. The use of a word or phrase depends upon both the recent and not-so-recent use of that word or phrase by other people. A word or phrase used in one situation, used in one way, may or may not be able to be used for the same purposes, or with the same meaning, in another situation. Words “lying ready in the mouth” of one
person may be significantly dependent upon the mouths of others wherein those same words were lying ready previously.

Moreover, unlike tools, words and phrases can never be used to fill a void where there were no words and phrases before. While a certain wrench may be the only thing suitable for turning a certain pipe, there are no words or phrases without which communication would simply stop. Words and phrases are not used to fill communicative voids because any would-be communicative void is itself steeped in a communicative event that is always already linguistically imbued. Not saying is a part of saying. Thus not saying and saying are in a relationship that is quite different from the relationship of being without a tool and being with one. Being without a tool is just that—it is a lack. Being without language is not possible in the same way as language never lacks; it rather turns upon a different meaning or a different interpretation whose silence is part of language itself.

Third, language cannot, as Dewey claims, be separated into intersubjective and cognitive elements. Gadamer insists that all language is fundamentally the language of dialogue:

... language has its true being only in dialogue, in coming to an understanding. This is not to be understood as if that were the purpose of language. Coming to an understanding is not a mere action, a purposeful activity, a setting up of signs through which I transmit my will to others. Coming to an understanding as such, rather, does not need any tools, in the proper sense of the word. It is a life process in which a community of life is lived out ... for language is by nature the language of conversation; it fully realizes itself only in the process of coming to an understanding (1960/1989, 446).

In language, there is in fact no “purposeful activity,” no “setting up of signs,” that can be separated from the to-and-fro of conversation. If there were such a purposeful activity alone, then language would not “fully realize itself.” Here one finds a stark contrast between Gadamer’s hermeneutics and Dewey’s linguistic anthropology. While Dewey indicates that language has, over the course of human development, taken on a second life as a purposeful activity, a setting up of signs, Gadamer maintains that language has not achieved its status as language if it remains symbolic and purposeful. Contra Dewey, the cognitive aspects of language are not an afterthought of language, a
derivative element of communication. They are instead only one step on the way to language.

Fourth, language is part of reality itself rather than being on a different ontological plane. As Gadamer maintains in his debate with Jürgen Habermas,

...there is no societal reality, with all its concrete forces, that does not bring itself to representation in a consciousness that is linguistically articulated. Reality does not happen "behind the back" of language; it happens rather behind the backs of those who live in the subjective opinion that they have understood "the world" (or can no longer understand it); that is, reality happens precisely within language (1976, 35).

These words by Gadamer not only elucidate what it means for language to be on the same ontological plane as reality. They also intimate the interpretive folly of those who would claim to get "outside" of language. As might be expected from discussions above, this one-world commitment is itself a common denominator for Gadamer's alternative understanding of language. For when language is not distinct from other matters in the world, then it cannot only take on the 'lighter' consequences of standing in for something more real. Nor can it be used as a linguistic means to some real end. Nor can it exist as something merely cognitive sometimes, something primarily intersubjective at other times. Language cannot, in fact, be identified as anything in particular because it is impossible to extract oneself from language in order to identify its defining limits. Language works as the rest of the world works by being a part of that world.

5.7. The Relevancy of Gadamer's Language Theory to Science Education

Gadamer's views have been introduced here for the primary purpose of contrasting his conception of language with that of Dewey and progressivism, not only because Dewey has played such a seminal role in science education in the past (and to lesser extent in the present; Fensham, 2004), but also because his linguistic assumptions continue to implicitly inform science teaching and practice in different ways. And while it is true that some earlier research (in the 1970s) had pointed out "how the assumptions
of teachers about knowledge and language in learning could be placed at one point or other” along a continuum from transmission to interpretation (Wellington and Osborne, 2001, p.25), one can readily acknowledge that the transmission model is ubiquitous (Mestre, 1991). There can be little doubt that even in most advanced science classrooms one often observes the nature of a discourse which assumes and exhibits those characteristics of language here described as representational/symbolic as well as instrumentalist in orientation while ignoring or misunderstanding language as dialogic and interpretive (also where it pre-forms the life-world of learners; Tobin et al., 1997)—all factors which, when taken together, usually create considerable barriers for student comprehension not only for learning targeted concepts (like heat, force or angular momentum) but especially for a broader nature of science conception (Kelly, 2007; Sutton, 1996; Duschl, 1990; Lemke, 1990).

An In-class Example

I choose as one example only (for the sake of brevity), the study by Roth et al. (1997) on physics’ teacher demonstrations, which illustrates several pedagogical points why students typically fail to learn abstract and mathematical, symbolic-framed concepts in senior classes, in this case angular momentum. This study seems to me to be indicative. A sampling, such as the following from the work of Roth et al., illuminates some common tendencies and problems that prevail in science classrooms today during the presentation of formal content knowledge, especially with respect to the role language plays—or is assumed to play—during demonstration interactions, including oral discourse and written text.¹⁹³ The authors were able to identify six dimensions of classroom dynamics that inhibited students from learning what the teacher intended during his demonstrations.¹⁹⁴ However, I will focus on only four of these in order to accentuate what is assumed and what is ignored by the teacher about the nature of language that tends to short-circuit the learning process. The sharp difference between an

¹⁹³ The study involved following an experienced physics teacher and his grade 12 physics students over a 6-week period, and combined data from several sources (e.g. videotapes, observations, post-tests, interviews and student notebooks).
¹⁹⁴ These were a part of other instructional practices involving formula-driven lectures, traditional numerical problem-solving, computer simulations and lab-based activities.
assumed transmission model of language versus a hermeneutic-interpretive one, I contend, is the major factor which underscores the learning problems at issue in at least four of the dimensions they identify. Below is only a vignette of one typical classroom discourse, taken from the study:

[The teacher] picks up a bicycle wheel and sits down on his turning stool, which is hidden from view for all but the students in the first row ... He invites students to observe ... He rapidly spins the wheel with its axis vertical—that is, parallel to the axis of the turning stool. This is associated with an almost unnoticeable opposite spin in his body. [He] comments, “This chair isn’t very good. I’ll try that again.” This time, the chair makes about a one-eighth turn. “Did you just see it? Look again, look at my body mainly. What was my angular momentum just now? Zero. I’m isolated, sitting in this awkward-looking position. When I spin it, what do you notice?”

[Student] calls out, “Opposite to the wheel.”

[Teacher] “Yes I’m going the opposite way to the wheel. When we are looking at these vectors, to start with, \( L = 0 \) was zero, wasn’t it? That’s my angular momentum. It’s made up of two things: my angular momentum and the wheel’s both \( 0 \), to kick off with.” [He] walks to the chalkboard and writes: \( L = 0 = L \) me + \( L \) wheel. He continues. “The angular momentum is the vector and has direction. This is how we measure the direction of angular momentum. You see, when I spin that, when it spins, if I put my fingers in the direction of the spin, my thumb comes out the axle.” (1997, 509-510).

In general, it can be inferred from the authors’ descriptions and analysis that the teacher makes unwitting use of a conduit-tool model during “show and tell”, supposing a classical transmission (“morse code”) model of knowledge acquisition (sender-receiver) and assuming its sufficiency to clarify the abstract concept of angular momentum.\(^{195}\) He also switches with ease, as scientific experts typically do, between multi-modal representations of the concept using the specialist language when explaining his active physical demonstrations (rotating on a swivel chair while spinning a counter-wheel balance).\(^{196}\)

\(^{195}\) “The teacher in this study ... was typical of many teachers in his transmission view of learning and teaching. ... He was very well-intentioned, but, bringing to this teaching technique an epistemological stance according to which the world was prestructured and knowledge matched this structure, overestimated what neophytes in physics could see in and learn from these demonstrations” (p.526).

\(^{196}\) By “multi-modal” we defer to the authors’ usage of the term to mean the various different ways to symbolically describe a vector “pointing up”. Such a vector, as in this particular case with common academic science discourse, stands-in for (or represents) the physical phenomenon of angular momentum. The authors describe at least four such representations (three graphic, such as “L”, and one physical “hand
What is revealed, however, is that student understanding and misunderstanding of
the event is determined by several language-based factors which have been overlooked,
which are inter-related—the so-called dimensions identified by the authors (“a number of
influences that mediated students’ descriptive and explanatory discourse”, p.520)—and
which can be re-categorized as follows:

i) language of a theoretical framework: without a background interpretive theory,
students cannot distinguish “signal from noise” during observations. In other words, the
language of prior theory structures what is seen and experienced. The scientist and
teacher are clearly at a distinct advantage over the novice in this regard, having
appropriated scientific theory and “seeing” already. In its absence,

ii) interpretive interference: other factors such as previously acquired “knowledge
bits” and preconceptions (themselves immersed in several in-and out-of school
discourses), as well as images of other demonstrations, largely contributed to their
interpreting what they saw being at odds with the teacher’s views (p.509, “interference of
discourses learned in other contexts of the physics course” and “interference from other
demonstrations and images that had some surface resemblance”);

iii) Confusion of disciplinary, theory-based representations linked to textbooks
and teacher talk: multi-modal symbol systems, required to represent and model physical
objects—which have now come to characterize modern science, especially technical
canonical language—are best acquired through use and by active participation in
discourse communities, which typical school students have little opportunity to explore.
“Students learn to manipulate symbolic structures without referential content and are not
provided with opportunities to integrate those symbolic structures that can be used
alternatively to describe the same system.” (p. 527); In that absence students, unlike for
experts, find it very difficult to combine unlike representations referring to different
aspects of a phenomenon (physical experience, mathematical symbols, graphics, hand
gestures for “right hand rule”, etc.), and which can indeed be taken to stand for objects in
different (linguistic) worlds. Hence,

and thumb”; p.527), although the typical (textbook) verbal or written definition should be included as a
fifth.
iv) Minimal opportunities for probing student science talk: because students generally were given limited chances to genuinely question and dialogue during the event about the observed phenomena, which could have helped surface their own understandings and preconceptions, they fail to correctly associate phenomena in ways compatible with the accepted scientific canon. In other words, they generally lack the awareness to develop the ability to compare and contrast their discourse with scientific discourse. "Students therefore had no means or opportunities to assess in which way their talk was inappropriate because, from a language perspective of knowing, competence in talking science requires participation in scientific discourse" (p.527).

These insights have been depicted before by Lemke (1990) and others, and while it can be admitted that the constructivist movement in science education has sought to rectify this imbalance (Llewellyn, 2005), classrooms which are immersed in a traditionalist culture primarily framed by formal knowledge acquisition dominated by lecture and high-stakes testing still suffer this charge (Tobin et al., 1997).

These points illustrate, I argue, the four Gadamerian perspectives on language stated above: that for the students in their attempt at understanding science, language performs more than just a representative or tool role, rather it is the medium of an interpretive event; moreover, it cannot be easily separated into intersubjective and cognitive elements, and it does not appear to function on two different ontological planes.

At first glance one could argue that aspects of this example could serve in fact to illustrate and reinforce Dewey's criticisms of traditional (science) education: while the instructor does assume a conduit model of language, as a “tool” it is used poorly (solely) to transmit information into “students’ heads”; this serves, moreover, as an end unto itself without any application (“pure knowledge”) where the teacher as authority figure (along with text) dominates the conversation (by controlled triad of “question-response-evaluation” or “I-R-E”; Lemke, 1990) and where active discussion and participation in the event (through action and genuine dialogue) is minimized. Dewey may even have pointed out that it shows how language remains at the level of “verbalism” (word or symbol disconnected with the object), and that learning had not occurred (could not
occur) precisely because the cognitive element had dominated the intersubjective, thus proving his assumption of the separation of elements.\(^\text{197}\)

Some of these comments appear to have force (and one can grant such an interpretive progressivist lens can be fruitfully employed to criticize aspects of conventional classrooms), but let us look a little more closely. Notice how the instructor has chosen an object from the “personal experience” of students (a demand of progressivism), for he sits and tries out various movements on a swivel chair, and yet they fail to learn what he demonstrates. So, in effect he has provided what Dewey always insisted on, to connect the abstract “map” with “the city” as it were, in this case, the representational scientific language with real life application.\(^\text{198}\)

It is certainly true that Dewey insisted that a kind of hypothetico-deductive problem-solving approach (“method”) with active peer engagement and talk should exemplify all school experiences if they are to be “truly” educative, and that science education would ideally serve as the paradigmatic model to illustrate this (1938, p.81). Hence, in returning to our example, to further justly meet Dewey’s criteria the students should have been allowed to not only swivel around in chairs (direct experience) but have

\(^{197}\) In short, Dewey’s main thrust, to be fair, would undoubtedly have been to reinforce his broader emphasis, that education as solely focused on pursuing “academic rationalism” as this case exemplifies, must fail, whereas his focus on “socialization” would be effective (using Eisner’s (1985) terms) since it would likely have framed the demonstration within some wider project of the application of momentum to life. The teacher’s role requires exactly the successful bridging of this (difficult) task, through insight and ingenuity to make the appropriate linkage of subject matter with the student’s immediate life-world to eventually attain structured disciplinary knowledge (1938). Needless to say, this does not seem to be possible with many key concepts and theories of modern science (e.g. chemical bond or plate tectonics)—all of which are very far removed from students’ language and life-world. One finds great problems also in going the other way—the Deweyan principle that starting out with life-world and using problem-solving inquiry would somehow lead both the educator and student to eventually arrive at such abstract, hidden and theoretically complex schemes: that somehow students’ questions and manipulations at the macroscopic level will open up formal knowledge at the super-microscopic or super-macroscopic (cosmic): “…so that learners may gradually be led, through the extraction of facts and laws, to experience of a scientific order, sets one of his [teacher] main problems” (1938, p.80).

\(^{198}\) Though, again, here someone may wish to object and add that it is the teacher and not the student that is being active, and so the learner is not directly involved and does not personally experience “the object” under discussion; hence for them, the physics’ symbols still remain detached from the object, the “word from the thing”. This argument is a qualification of Dewey’s view, and even if granted it is the experience of my physics teaching that having had students practice on their own swivel chairs did not help them better understand the concept either. And this activity involved intense discussion on their part, hence making use of language as intersubjective tool. Such comments may be anecdotal and isolated, but they help point out that there is more to learning science that just skillfully linking the language of a scientific discipline (“the cart”) to the personal experience and social environment of the learner via intersubjectivity (“the horse”; see his (1945) description).
transformed this opportunity, using the teacher's guidance, into a problem-solving activity on its own and thus, through the social use of language somehow manage to co-construct with that experience and external guidance the formal knowledge and language of science in the process. This is, as a matter of fact, similar in expectation to what "guided inquiry" approaches and some constructivist views of learning and knowledge have continued to suggest, although such views have now been heavily criticized from different perspectives. 199

**Hermeneutics, epistemology, and the role of language in classrooms**

The buried supposition appears to be, certainly for Dewey and others, that the everyday language-world of students can be led to, or perhaps somehow enabled to co-create, scientific language providing the correct linguistic intersubjectivity, personal experiences and manipulative elements are established. Only then will the abstract, symbolic language of science link up with student meaning and allow "symbol to join up with thing"; only in this way will the language as instrument be used wisely, not solely as conduit for knowledge as ends, but as tool for social purposes (citizenship), when it subsumes the cognitive element under the intersubjective one—that is, the 'tool' used to enhance thinking will be brought under the social-communal value of knowledge-building through problem-solving, and so extend experience for Furthering thought and democratic life. But this supposition, regrettably, is not borne out, as several decades of conceptual change and constructivist-based research on alternative conceptions has shown—students' often erroneous, substitute views and interpretations of phenomena are remarkably resistive to strategies seeking a switch to canonical constructs (Duit and Treagust, 2003; Duschl and Hamilton, 1998). This can be partially attributed to the fact that their 'scientific' ideas are not held in isolation, independent of the conceptual-semantic net of their language and life-world (Nersessian, 1989). They will rarely be 'teased out' and replaced solely through intersubjective talk, no matter how well-

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199 Either because they erroneously assume an inductive epistemology lies behind science and undervalue the power of prior theory (Duschl, 1994, 1990); or that student inquiries and epistemologies are capable of constructing in some fashion established scientific ones very far removed from "common experience" (Matthews, 2000; Osborne, 1996; Hodson, 1996; also Kirschner et al., 2006).
intentioned or appropriate the direct experience and problem-solving milieu—but this is not to say such factors are entirely unimportant.

Vygotsky (1986) of course, had much earlier alluded to the different natures and sources of the two kinds of languages in classrooms, the ‘scientific’ and the learner’s ‘spontaneous/everyday’ discourse, and the important interaction of the teacher-learner in the zone of proximal development (ZPD), where the culture-bound and technical scientific language can begin to be internalized. Moreover, and bearing this in mind, our example then also illustrates that the Deweyan assumption of the ontological two-world commitment does not hold—recall that this is the bedrock of his other three assumptions. The language-worlds of students and of academic science represent if not incommensurate linguistic worlds (which hermeneutics does not allow), then nonetheless “separate worlds” which must be brought together in an altogether different kind of way or situation in order for student understanding to take place, one we call the hermeneutic experience, and one which has been appropriately described by Eger (1992). While it is true that the Vygotskian perspective has been useful as an explanatory lens in science education, and while we maintain that it helps further undermine the aforesaid Deweyan assumptions of language, Nonetheless a Gadamerian perspective presents yet another alternative view of language and how students come to learn.

As a general rule, the nature of language and how it is used in classrooms can be roughly categorized as an interplay between three essentially different discourses, involving those of the scientific community (including textbook and canonical knowledge formulations), the teacher and the student. This can equally be viewed, appropriating instead Wittgenstein’s terminology, as the case whereby each is situated in their own respective “language game” (1953/8). The three-way interaction of these discourses (or

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200 See Leach and Scott (2003, p. 99): “Following the process of internalisation, language provides the tools for individual thinking. Central to this view is the continuity between language and thought. It is not the case that language offers some ‘neutral’ means for communicating personally and internally generated thoughts; language provides the very tools through which those thoughts are first rehearsed on the intermental plane and then processed and used on the intramental plane”.

201 Leach and Scott allude to limitations inherent to the Vygotskian notion of internalization, in that “there is no recognition of the different forms of intermental functioning which occur on the social plane” (p.99) which must contribute to the process. Secondly, it is not clear how the so crucial internalization process happens, though as originally envisioned it was not one of simple transfer. Interesting for us and our hermeneutic perspective, is the view of some authors that it involves “personal interpretation”, whereby “the individual comes to a personal understanding of the ideas encountered on the social plane” (p.101).
"three-language problem"), as can be expected, can serve to either improve or, on the other hand as is only too frequent, undermine scientific literacy (Figure 3). That is, it serves to increase or decrease interest in science (affective dimension), as well as validate or misrepresent the nature of science (NoS) in the minds of students (cognitive dimension), depending upon how science is understood and how scientific knowledge is framed. In most cases, what is often revealed through the expression of these discourses (whether in verbal or written form) in classrooms—which are themselves intimately tied to their own underlying epistemologies (of the textbook, teacher and student)—is a dogmatic and philosophically out-dated portrayal of science (Matthews, 1994; Lemke, 1990). According to the socio-cultural research tradition, conceptual conflicts that students encounter originate not primarily due to conflicting cognitive mental models (according to prevailing conceptual change theory) but more so in conflicting multiple discourses, each linked to its own community of practice, and in which the cognitive models are necessarily embedded and find their expression (Anderson, 2007; Klaassen and Lijnse, 1996). It is precisely such insights and the conceptualizing of the classroom as a linguistic field of contending multi-discourses that corresponds closer to a Gadamarian outlook on language, I contend, than a conventional progressivist one.

With the growth of the socio-cultural research tradition in science education, as stated before, has come the realization that the model of language as used both in science and science education is not only or primarily one of useful conduit and representation (or symbol and tool), but equally and perhaps more so one of discourse and interpretation (Kelly, 2007; Sutton, 1998; Gregory, 1988). We concentrate here on the latter and ask: “What is the role of interpretation in the understanding of science?” (Eger, 1993a, p.11).

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202 Term employed by Yore and Treagust (2006, p.296): “A three-language (home language, instructional language, science language) problem exists for most science language learners that parallels English language learning and involves moving across discourse communities of their family, school, and science. No effective science education programme would be complete if it did not support students in acquiring the facility of oral science language and the ability to access, produce, and comprehend the full range of science text and representations”.

203 We certainly recognize similarities in the hermeneutic language perspective to insights of researchers in the socio-cultural tradition who have been inspired by other comparable socio-linguistic-based views, such as, for example, Bakhtin: “Saying that different social languages ‘are specific points of view on the world, forms for conceptualizing the world in words’ [quoting Bakhtin] provides a warning against treating students’ ideas as if they were solely individual constructs, independent of the language used to express them, and against treating language simply as a channel or conduit for communicating ideas” (Mortimer and Scott, 2000, p.128). See also Kubli (2005).
It of course belongs to the essence of the discipline of hermeneutics that the notion of interpretation stands at its core, for it has developed historically as the scholarly pursuit of understanding the meaning of ancient foreign language texts via theories of interpretation.\(^{204}\) We are already accustomed to the view that one needs scholars to interpret ancient manuscripts, and that today different interpretations exist for religious texts and laws, or novels, poems, plays and movies. What is not so common is to view either education or the scientific enterprise exclusively in this light.

### Figure 3. Three Language Problem

<table>
<thead>
<tr>
<th>Specialist Science Language</th>
<th>Language linked to Everyday</th>
<th>Science Education Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language special to the subject</td>
<td>Language special to the subject but which is linked to student's everyday or home language</td>
<td>Language not common to the student's world outside school.</td>
</tr>
<tr>
<td>Terms, ideas and forms of language unique to the subject which teachers are aware of as a potential problem and therefore present and explain to their students explicitly</td>
<td>Terms, words and forms of language which may not be deliberately presented because teacher is unaware problems are caused by familiar words being used in more specific ways</td>
<td>Terms, words and forms of language used by teachers which pupils would not normally hear, see, or use except in the world of science classrooms</td>
</tr>
<tr>
<td>e.g. trachea amoeba/ cytoplasm neuron/ subconscious photosynthesis/ osmotic equilibrium saturated refraction cathode ray electrolysis ion / ionization Isotope emulsion metabolism</td>
<td>Kilojoule unit amplitude atom/ molecule fusion/ fission torque respiration Homeostasis entropy law theory weight friction star consumer / property</td>
<td>e.g. work energy/ excite/ radiation/ heat field/ current/ resistance power /excess cycle/ period substance impulse law theory weight friction star consumer / property</td>
</tr>
<tr>
<td>e.g. ideally random categories</td>
<td>principle characteristic of... crucial distinguish between... adjacent</td>
<td></td>
</tr>
</tbody>
</table>

Three Language Problem (Adapted: Wellington & Osborne, 2001; Yore & Tregaug, 2007)

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\(^{204}\) The English word “interpretation” comes from the Latin *interpretatio*, which is itself a translation of the Greek verb *hermeneuein*, “which means to express aloud, to explain or interpret and to translate” (Schmidt, 2006, p.6).
One invaluable answer is provided by Sutton (1996). I mention him here chiefly because his analysis contains vital aspects of a hermeneutic view of language but without the acknowledgement of this perspective. His analysis of how the language of a scientific idea changes from its initial formulation to how it later becomes rephrased, codified and depersonalized through the different stages of publication—passing from discovery to research paper, handbook and finally textbook—uncovers the often neglected aspect of the development of scientific concepts themselves, in other words, the historicity of scientific language and theory. (Gadamer foregrounds the importance of the historicity of human consciousness, thinking and language). He has argued that students’ beliefs about science are shaped by their beliefs and use of language, and has illustrated how these are in turn shaped through textbook ‘talk’ and classroom conversation. He has described how students encounter two possible and different conceptions of language in school science, contrasting language as a labeling system (the dominating one) with language as an interpretive system (for making sense of and sharing experience through open discourse; also characteristic of research science ‘at-the-edge’). The latter he ascribes to a “persuasion” view, while the former, in assuming an unproblematic labeling system, corresponds to a “transmission” (“morse code”) view of communication, instruction and knowledge—also to our previously described “symbol” and “tool” conceptions (Figure 4). I note—in agreement with Roth et al. (1997) and our previous example—as such, it implicitly takes on board a form of epistemological objectivism and naïve realist stance:

From a classical perspective of knowing and learning, [the teacher] has done many things appropriately. A classical perspective of knowledge treats it in modular form. Words (concepts) have meaning and refer to ontologically real objects. Looking at real objects and events provides a direct view of the concepts. Through observations, individual students are enabled to see the underlying structure. The teacher has only to provide the correct labels (we note that this is also a central part of other teaching strategies such as the learning cycle) (p.528)
Figure 4. Two Views of Science as Influenced by Language Use
(Based on Sutton Beliefs about science and beliefs about language, 1996)

View #1: "Common sense" view: Textbook influenced epistemology and Language

*Science taken as "Finished Product" and Pseudo-Historical Myth

FACTS obtained by observation and experimentation \( \rightarrow \) Summaries of scientific knowledge about the world (laws and theories)
(simplified inductivism as method) (theories as ‘discovered’)

"Factual language"; Words a labels \( \rightarrow \) Memorize ‘facts’ and processes and confirm by algorithmic problem-solving

RESULT:
- accumulated/ahistorical facts as starting point; discovered and ‘ready-made’
- Language taken as representation; “morse-code” notion of teaching & learning
- expository language is impersonal; narrative language is missing

View #2: Alternative view: HPS influenced epistemology and language

*Science taken as “In Process” and Historically Dynamic

HUMAN THOUGHT and creativity/ imagination; speculation/ struggle
- Conjectures
- Historical revolutions
- Theory-driven research and observations combined with community scrutiny \( \rightarrow \) Claims
- attributed
- confirmed \( \rightarrow \) FACTS
(Distilled and filtered textbook knowledge)
“Fixed Science”

“This is how it IS”
(Literal language)
Words as labels
Language as Transmission

“Think-of-it as …”
(Figurative, metaphorical language)
Words and concepts as interpretive
Language as Interpretive

RESULT:
- Facts as the end point of a long historical development/struggle, and starting as tentative speculations/ideas in ‘frontier science’ (Historicity of concepts).
- Language is transformative; it serves different functions
- Narrative is partly personal/humanized (‘science stories’; History of science)
It is not only in teacher demonstrations, but as Sutton argues more broadly because of the pervasiveness of the “labeling” aspect of language and its mode of use (in textbooks and classroom discourse generally, when privileging the transmission model) that it directly contributes to misrepresenting the development of scientific ideas and process of research inquiry. “With such a limited sense of what language is for, and lack of experience in actively using it, [students] carry too simple an idea of science as fact-gathering and of language as fact-labeling, and they can become increasingly disadvantaged as learners” (1996, p.13). Science facts, concepts and laws are then mistakenly understood (“common sense view of science”) as forming the starting point for curriculum and teaching (to be memorized, used in equations, or inductively “re-discovered” in lab-based activities), rather than being revealed as the end point of an arduous historical and critical inquiry approach: originating in human imagination and discovery, remaining tentative, requiring confirmation and correction in professional discourse communities, and only much later re-interpreted and structured according to the complex conceptual web of the specialist language of an established discipline.

In other words, a very restricted and (sadly) widespread notion of science, also termed “final form science” by Duschl (1990), is deliberately inaugurated and reinforced by how both textbooks and science disciplines use language to structure knowledge as curriculum—as a finished product. What results is a grave distortion of the nature of science (NoS) as a “rhetoric of conclusions” (Schwab), as others have often pointed out,205 but I echo Sutton that such consequences are closely correlated to how language is used and understood—invariably a deceptive epistemology of science becomes codified and reproduced in both textbook and teacher epistemologies. More to the point, such a consequence must come about according to a hermeneutic perspective, because language—ironically—is here shown to be expressly not functioning on two separate ontological planes. Dewey correctly identified the “final form” problem, as I said earlier, but pointed to the wrong conception of language as part of the solution.

205 Students come to receive the impression that knowledge is static, ahistorical and decontextualized; facts are to be inductively “read off nature”; scientific method is singular and straight-forward; problems are to be solved algorithmically; and that essentially science is uncreative, impersonal and value-free. In other words, “epistemologically flat”, “ontologically exact” and “sociologically neutral.”
Another answer regarding the role of interpretation and language in understanding science has been provided by the late physicist and philosopher Martin Eger. In a series of important papers (1992; 1993a,b) he has presented a cogent and comprehensive analysis of Gadamerian hermeneutics and its relevance especially for science education. His work is complimentary to that of Sutton and I spotlight briefly some of his compelling insights, mentioning three important aspects of his analysis pertaining to: interpreting science, the problem of misconceptions and the contexts of science and science education.

Eger accepts Gadamer's universalist claim for hermeneutics, that it inheres to "the whole human experience of the world" (1976, p.15), especially in art, history and law, and that essentially any case of understanding requires interpretation, which necessarily presupposes the domineering nature and role of language. Yet he boldly extents this claim (alongside others) to an understanding of natural science itself; above all to science education in a novel move that Gadamer had not foreseen—though it can be rightfully taken to orbit in the region of Gadamer's broadly formulated original claim. Eger (1992) had initially distinguished between two different kinds of hermeneutic activities that are possible: one which we can characterize as the direct study of nature herself (science as inquiry or "frontier science") versus the study of science as a discipline (science as a body of knowledge, or "textbook science")\textsuperscript{206}; the former comprises the probable hermeneutic activity of the researcher ("research situation") and the latter the hermeneutic activity of the science learner ("educational situation"). Both are also immersed in language: the first being traditionally associated with an assumed "language of nature" or "book of nature" (a term going back at least to Bacon and Galileo), while the second is associated with a paradigm-bound "language of science", and now widely accepted even within different science education traditions as presenting an obstacle to learning for the novice (Wellington and Osborne, 2001; Lemke, 1990). It is to this second case, the "educational situation", that we briefly turn to, and avoid here

\textsuperscript{206} These are terms I have suitably borrowed from Bauer (1992).
completely the worthy and contentious conversation about the hermeneutic status of the first (Hiley, et al., 1991).  

Eger equally fronts the problem of language as the central one in science study in correspondence with current concerns of language-focused research, yet provides distinctly alternative hermeneutic answers to this issue, including addressing the linked and well-researched problem of student misconceptions or preconceptions. By laying stress instead on several key Gadamerian notions such as surfacing prejudices or “fore-knowing” (equivalent to “pre-conceptions”), by having learners enter the “hermeneutic circle” of understanding in the correct way, and by providing opportunities for the student and the science ‘text’ to “fuse their (interpretive) horizons” (the actual process in which understanding can be said to occur), he offers perceptive and practical solutions to some well-known problems of science learning. An unusual but fruitful perspective is one where science study in general is looked upon “as the interpretation of the language of science, and upon the teacher as the chief interpreter” (1992, p.341), and in his papers he insightfully sketches out the ramifications of that view. The hermeneutic perspective may even prove beneficial when comparing where existing conceptual change theories of science learning are shown to be inadequate, rooted in either psychological-based constructivist models or philosophy of science analogies (Duschl and Hamilton, 1998).

This perspective has much to offer as potential for new directions in future research work, as some current researchers have discovered (Kalman, 2009; Borda, 2007).

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207 We should mention however, that Eger in his later papers (1993a,b) presents fascinating arguments why also “research science”—and even conceptual developments within given scientific paradigms over time—exhibit typical hermeneutic dimensions and therefore science itself can be considered, to the contrary of many prominent views, as a true form of hermeneutic activity. (By providing evidence from the writings of some scientists, like the physicist Richard Feynman and the biologist Barbara McClintock, and akin to the views of some philosophers of science, like Heelan (1991) and Hesse (1980)).

208 In Eger’s view what is required is a fundamental shift in the teacher’s and student’s notion of knowing and learning, away from an epistemological focus to an ontological experience of “being-in-the-world”, that is, “bridging the horizon of physics and the horizon of the lifeworld implies an extension of language and of concepts (Bevilacqua and Giannetto, 1995, p.117).

209 The authors reference the research of Pea and the emphasis on the crucial role of communication (or dialogue in Hermeneutics) in conceptual change: “crucial aspects of learning can occur within a context of conversations in which production and interpretation of communication drive the construction of meaning. Rather than being viewed as the messenger of knowledge and meaning, communication is viewed as the location for the creation of knowledge and meaning” (p.1053). The role and nature of dialogue, as mentioned, is fundamental to Gadamer’s ontological conception of language, meaning and understanding.
Finally, a third aspect of Eger’s analysis regards the contexts of science and science education. Traditionally only two contexts have been identified (originally formulated by positivist philosophers to define the proper field of study for philosophy of science), being the context of justification and of discovery. The segment of science education literature which has been critical of the epistemology of school science and focused on reforms linked to incorporating appropriate history and philosophy of science (HPS) themes into curricula and teacher education programs, has come to stress the value of the context of discovery (“how we know”) along with the dominating context of justification (“what we know”) in classrooms as essential for a more comprehensive understanding of science (Monk and Osborne, 1997; Matthews, 1994; Duschl, 1990). While I certainly agree with and support these reform efforts, I would nonetheless reinforce Eger’s novel insight that a third context of interpretation (1993b, p.321) has been fundamentally overlooked in the overall critical discussion within both philosophy of science and science education. And where not overlooked then certainly misunderstood and minimized, although its presence has always existed and been embedded within the historical and conceptual development of science (its theories, aims and methods) and within the “educational situation” especially.\footnote{The ramifications of this perspective has been discussed by some authors, pertaining to the nature of science (Hiley et al., 1991); the formalist versus interpretive debate in quantum mechanics (Cushing, 1998); and science education with respect to the historicity of science, of textbooks and understanding (Bevilaqua and Giannetto, 1995).}

5.8. Summary
This section has concentrated on the nature and role of language in science education with the specific focus of contrasting the different perspectives on language as found in two seminal 20th century thinkers, John Dewey and Hans-Georg Gadamer. It is argued that Dewey’s linguistic assumptions behind his progressivist philosophy—especially as found in his many early and middle works—remain largely unexplored and problematic while they continue to resonate and detrimentally affect science learning. Although his legacy in science education was appraised, by critical comparison and analysis these assumptions were made explicit while providing exposure to an alternative understanding of language as offered by the philosophical hermeneutics of Gadamer. While this
composed the main body, an example was provided to illustrate how the "symbol and tool" conception of language in classrooms is dominated by a transmission model reinforced by a representational epistemology that hinders learning. It was recognized that Dewey was himself critical of such a view of language and epistemology taken alone, and especially in his last work (in 1949) had sought to overcome through his pragmatic "transactional inquiry" the dualism that characterized so much of Western epistemology (and educational philosophy, too). He moved towards a more "dialogic" view of language-in-use—very similar to the later Wittgenstein—although his previous notions continue to be spread widely in science education. It was inferred instead that in typical science classroom discourse that language actually functions in ontological-hermeneutic mode and while this is generally unacknowledged in science education a shift towards a perspective which recognizes both the dialogic and interpretive dimensions would be beneficial. As well, explicit links were made to other research exploring hermeneutics in particular, and the language-based socio-cultural tradition in science education in general.

My own analysis goes hand in hand with these latter linguistic/hermeneutic approaches. But as was attempted in this section, things are not as simple as adding a linguistic approach here, or utilizing a hermeneutic style there, when it comes to proceeding toward a progressive science education that is truly progressive. It was shown that the problem runs much deeper, that a thorough treatment of language as something other than a symbol system must be established, and contextualized, in relation to what has formerly been considered "progressive" science education. This will be a linguistic treatment of science pedagogy that not only moves beyond the "two-world commitment", but gets past the verbalism/experience dualism that, as was asserted, has typified progressivist inspired education since Dewey’s time and the various iterations of his popularity. In a sense, then, what is being advocated is a science education, properly understood, that is "more Deweyan" than Dewey’s. John Dewey indeed identified some of the central problems that would continue to plague science: science pedagogy is still too often preoccupied with a notion of language that assumes its primary role as a 'pure' symbol system, as a tool either to be used in the transmission model or misused to reinforce an authoritarian image of science, of the textbook and the teacher’s role while
constraining or ignoring its vital socio-communal dimension and means for socio-
educative ends. And while Dewey recognized that often language appears to function on
two separate ontological levels (due moreso, now widely recognized, as a fiction-
category of our analytical thinking), contemporary classroom science education usually
assumes a labeling system, a simple and direct correspondence between the
representation and the object signified, itself revealing a simplistic objectivist
epistemology underlying curricula and teacher talk. As a result the nature of science
(NoS) becomes distorted and science learning is stultified, but not because the character
of language is as Dewey believed (although partly accepted as operating in dialogic
mode), rather precisely because symbol, tool and cognitive elements linger as a part of
one-world of language as being, as experienced and lived in its ontological and
interpretive-hermeneutic dimensions.
CONCLUSION

The value of philosophy for science education remains underappreciated at both pedagogical levels discussed, whether one examines the research field or classroom practice. This is further exemplified by the ongoing neglect of studies in philosophy of education by science educators, an underdeveloped area. The main concern of this Thesis has not only been to draw attention to these issues but to make the case for the academic and pragmatic establishment of “philosophy of science education.”

The worth of such a discipline-specific philosophy in essence lies in its power to perform critical inquiry at both levels, improving science education as a research field and science teacher education. In the first instance, to impel the discipline to clarify its identity and re-examine its goals (especially scientific literacy), foundations, “reform waves,” research methods, and dependence on theories from outside disciplines, as well as determining the suitability of educational metatheories and scrutinizing the nature of scientific epistemology and practice germane to science education. In particular to deconstruct social-group motivated interests and ideologies. These are some key problems but by no means the only ones comprising the scope of its inquiry at the level of critique and research. But it implies opening up a fourth inquiry field (next to the common quantitative, qualitative and emancipatory).

For the second case with respect to teacher education and transforming pedagogy, the ability to equip the classroom teacher with a “second order” reflective capacity when teaching or curriculum planning. As an integral component of practitioners’ Pedagogical Content Knowledge when decision-making, science teachers would recognize the need to problematize the common content knowledge for two reasons: firstly, to transpose the disciplinary-based science subject matter into a meaningful form accessible to the learner at age-appropriate grades, and secondly, to broaden the knowledge base to reflect more authentic epistemological and sociological aspects of science and its development. (At minimum a critical-mindedness is sought to avoid perpetuating the “scientism” and pseudo-history of curricula plus helping dispel anti-science attitudes among pupils). The former requires an understanding of the worth and function of educational metatheory while the latter requires an understanding of nature of science discourse gained through “science studies”, especially developments in the fields of history and philosophy of
science. The History and Philosophy of Science (HPS) reform movement has made major
contributions to support teachers in their duties.

Another further aspect of teachers' Pedagogical Content Knowledge which a
philosophy of science education can help develop is an improved understanding of the
role and nature of language, whether found in active dialogue or how knowledge is
framed in the historico-epistemological structuring of content in textbooks. Instructors
need awareness and assistance to move beyond teaching only "final form science" of
current paradigms, therefore the historicity of scientific concepts and theories must be
recovered. Above all, the ubiquitous symbol and tool conception of language behind the
"transmission" mode employed in classrooms must be amended for a hermeneutic
influenced "interpretation" conception, with the perspective that "language as being"
influences a student's life-world, hence how they learn and make meaning of texts.

To illustrate the tasks that philosophy of science education can perform when
contributing to the advancement of the research field, three different philosophical
analyses were undertaken, respective to studies in the fields of philosophy of education,
philosophy of science, and philosophy of language. Respective to the latter two, detailed
case studies examined the realism/instrumentalism debate in the philosophy of science,
and scrutinized Dewey's language views from a Gadamerian hermeneutic perspective as
an example of a central dispute pertaining to philosophy of language.

When bringing to bear the worth of philosophy of education two educational
metatheories were compared and contrasted, the influential German-Norse Bildung
tradition and Egan's cultural-linguistic theory. The merit of metatheories in general lies
in creating curricular coherence and steering educational aims. It was argued that Bildung
suffered disadvantages due both to its inherent conception and its implementation. Its
defining characteristics harbour educational ideas in tension with each other while
implementation efforts have resulted in opposing educational aims ensuing from diverse
interpretations of these conflicting ideas. Egan sidesteps the common quandary of trying
to balance three traditional educational ideas (knowledge, personal development,
socialization) and reconceptualizes the educational endeavor to focus on developing
students' cognitive-emotive tools of understanding at appropriate age-developmental
stages. Such a conception of education and its goals could redefine the notion of scientific
literacy, since current notions of the concept are also at odds—this being due, it was argued, to the definition suffering from the same conflicting three ideas that equally afflict Bildung. Moreover, Egan questions the worth of psychological metatheories for education, and seeks instead to gain autonomy for educational studies and theorizing. Educational development was contrasted with psychological development, and narrative understanding was chosen over against the more common conceptual change model for learning science. It was further argued that science education could be liberated from it dependence on learning theories in either psychology or philosophy of science analogs, as well as from socio-utilitarian ideologies, if it managed to accommodate educational metatheory and orientate itself primarily as a sub-discipline of educational studies. Because all “mature” sciences (natural or social) are marked by high-level theories which command their disciplines, it was advised that such an endorsement of educational metatheory could provide further grounds to establish its identity and indicate its progression as a more “mature”, independent discipline.

The value of philosophy in itself as I have attempted to articulate its worth for science education will only be taken on board in so far as both researchers and practitioners will be convinced by the presentation of the arguments and the case studies. Philosophy does not come easy. It is demanding of time and considerable mental effort. Hopefully the benefits have been sufficiently elucidated to justify the exertion, including the merit of its contribution towards addressing and clarifying some fundamental issues and long-standing science educational problems—perhaps its real worth will only come to be fully recognized by the community when the “crisis” flag is raised once again.

It is important to emphasize that the proposed case for a “Philosophy of Science Education” (POSE) at this point is an initial undertaking and a cross-disciplinary research project. The entire purpose of suggesting a search is to open up new ground and offer some solutions for science educational reform with the understanding that the issues raised and ideas presented will serve as a catalyst for further research and continued work, not only by the present author but along with other parties which have already expressed an interest in further collaboration. This Dissertation is the presentation of an initial stage of a project-in-progress which, it is hoped, has the potential to become a new international joint venture in science education.
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