

Design Strategies for Collaborative Learning in Tangible Tabletops: Positive Interdependence and Reflective Pauses

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This mixed methods study examined the impact of two design strategies on interactional processes in a collaborative tangible-tabletop land-use planning simulation. Twenty pairs of fifth grade children used the simulation to create a world they would want to live in. To investigate the impact of positive interdependence half the pairs were assigned one of two roles, each with an associated set of tangible ‘land-use’ stamp tools. All pairs were given access to pause and reflect tools. Quantitative results showed that children in the positive interdependence condition gave more one-way explanations to their partners than control pairs. They also had fewer but longer instances of bilaterally resolved conflict. Qualitative findings indicated the importance of pause and reflect tools for provoking explanations and resolving conflict. This study has revealed important considerations for the instantiation of positive interdependence and reflective pauses in collaborative tabletop learning systems, showing both quantitative and qualitative differences in the interactional processes that result from these design strategies.

CCS CONCEPTS.

Human-centered computing → Empirical studies in collaborative and social computing.

RESEARCH HIGHLIGHTS

- This paper presents an in vivo experimental study of the effects of positive interdependence and reflective pause design strategies for creating collaborative learning applications on tangible tabletop platforms;
- The findings from a mixed methods analysis explicates how these design strategies stimulated interactional processes, including explanation giving and conflict resolution, that support learners to reach common ground in a collaborative learning task;
- The *positive interdependence* design strategy of creating system contingencies through tightly coupled tangible inputs combined with leveraging social practices related to assignment of roles and tools was associated with more explanations involving externalization of thinking, world inhabitant perspective taking and strategic level joint problem solving of conflict;
- The *reflective pauses* design strategy of having several universally accessible tools that could be used to stop interaction and provide world state information was associated with learners taking actions to jointly explore the task and come to better understandings of the task and each other’s perspectives as they negotiated toward common ground;
- While the insights from this work are situated in the design space of tangible tabletops, which are characterized by hybrid physical–digital systems and embodied interaction, the findings can likely be generalized to other hybrid, embodied technology platforms (e.g. augmented reality, virtual reality) that are currently gaining momentum in the space of collaborative learning.

1. INTRODUCTION

As computation increasingly moves off desktops and laptops and becomes integrated into objects and environments in our lives, it is important to understand collaborative learning in the design space of hybrid physical and digital environments (mixed reality). There is a plethora of hybrid, embodied technology platforms that support social–physical–digital forms of interaction in space, for example, augmented realities, virtual realities, tangible tabletops, interactive spaces, networked hand-held devices, augmented maker workshops, automobile user interfaces, human–drones systems, interactive surfaces, as well as other emerging platforms. We focus on tangible tabletops—an early and prototypical example of a hybrid, embodied platform for collaborative learning. Interactive tabletops are horizontally oriented digital surfaces that allow for direct physical interaction with digital media through multi-touch and/or tangible objects (Antle, 2014; Higgins *et al.*, 2011). Tangible objects (or simply ‘tangibles’) are digitally augmented physical objects that are recognized by, can affect and can be affected by the tabletop system (Ullmer and Ishii, 2000). When they were first introduced, interactive tangible tabletops were highlighted as a technology particularly suited for collaborative learning due to their ability to support simultaneous use, hands-on activities and multiple modes of communication (Dillenbourg and Evans, 2011). While tabletops have not yet been widely adopted in classrooms, recent analyses suggests that they fulfill an important gap in learning technologies (Müller-Tomfelde and Fjeld, 2012). Specifically, they have been suggested to have particular affordances for facilitating joint attention and a shared transaction space for reference, negotiation and action (Antle *et al.*, 2011; Fernaeus and Tholander, 2006; Winoto and Tang, 2019; Woodward *et al.*, 2018). Of course, opportunities for collaboration are not always taken up by learners; the literature contains numerous examples of interactive tabletops being used in undesired ways including independent parallel play, competition and domination by one learner (Falcão and Price, 2011; Jamil *et al.*, 2017; Marshall *et al.*, 2009). Thus, two central challenges in designing tangible tabletop applications for collaborative learning are finding ways to distribute activity across a group and getting group members to coordinate this activity by engaging with each other productively (Higgins *et al.*, 2011; Roldán-Álvarez *et al.*, 2020). These challenges also apply to many other instances of mixed reality technologies that enable social–physical–digital interaction. As such, strategies to address these challenges in the context of interac-

tive tabletops may generalize to interaction and learning design for other hybrid, social and embodied technology platforms in which small groups of people interact with each other, with objects and with computation in a spatial environment.

In this paper, we investigate how specific design strategies for tangible tabletop systems create affordances to support the interactional processes of collaborative learning, conceptualized as activities that support the negotiation of common ground. The design strategies we pursue involve creating affordances and/or opportunities for positive interdependence and encouraging reflective pauses. The focus of our experimental investigation was on positive interdependence, a well-known learning design principle in collaborative learning (Johnson and Johnson, 2014). Positive interdependence refers to the extent to which group members must rely on each other for effective actions. The main goal of the study was to investigate our proposed interaction design strategy (which included both technical and social components) for supporting positive interdependence in tangible tabletops. We also evaluated a second learning design principle for mixed-reality environments: encouraging reflective pauses. Encouraging reflective pauses refers to approaches that both provide a reason to reflect and offer the time to do so (Antle, 2014; Price *et al.*, 2010). Based on prior work, we hypothesized that reflective pauses are important for creating opportunities for negotiation in collaborative learning and therefore this design strategy must be considered as part of the enabling conditions for our investigation of positive interdependence (Antle *et al.*, 2011; Antle and Wise, 2013).

To investigate the instantiation of these two design strategies for tangible tabletops and their effects on collaborative learning processes we built a sustainability simulation called Youtopia. Youtopia lets learners build a world they would want to live in, taking into account both human needs and environmental conditions. We chose the domain of sustainable land-use planning because (i) it is inherently spatial and thus well suited to the large tabletop display surface; (ii) the topic is complex with many inter-relationships making it well suited to a simulation (Antle *et al.*, 2011); and (iii) it involves individual and societal values, thus able to benefit from collaborative negotiation processes about not only how goals should be achieved, but also which of multiple viable goals are worth achieving (Suthers, 2006).

The study reports on an explanatory mixed methods study (Creswell and Clark, 2011) with an experimental manipulation

of our design strategy for positive interdependence (called ‘roles’) of 40 fifth graders using Youtopia. Quantitative analysis was used to investigate *whether* our design strategies supported the desired interactional processes of working together, explaining reasoning and resolving conflict jointly, while qualitative examination extended these findings by probing *how* and *when* they did so. While explanatory mixed methods studies often collect separate data for the quantitative and qualitative aspects of the work, this kind of design can also be enacted through the use of a single data set that is analyzed first quantitatively and then qualitatively. The results of the quantitative analysis can be used to produce the sample for the qualitative analysis (for examples, see [Paulus and Wise, 2019](#); [Rasmussen, 2015](#); [Wise et al., 2020](#)). An important contribution of this work is understanding the ways that learners interact with technological tools that were designed to support positive interdependence and encourage reflective pauses in collaborative learning. In previous publications (*removed for blind review*) we focused on a subset of constructs and data and framed findings mainly from a learning sciences perspective rather than that of design. In this paper, we draw on and extend those findings, reporting on additional constructs and data (e.g. qualitative analysis of conflict-resolution events) and framing findings from the perspective of design guidance for collaborative learning.

2. COLLABORATIVE LEARNING AND TANGIBLE TABLETOP DESIGN

Understanding the affordances technologies offer for meaning-making is foundational for computer-supported collaborative learning (CSCL) ([Jeong and Hemlo-Silver, 2016](#); [Rosé and Dimitriadis, to appear](#); [Suthers, 2006](#)). Specifically, we focus on investigating practices of meaning-making through understanding negotiation processes and the ways in which these are mediated by design ([Stahl and Hakkarainen, to appear](#)). With tabletops, the artifact is a large horizontal surface with which learners can interact through multi-touch and/or tangible input objects. Tabletops are distinguished from many CSCL technologies in that they are intended for co-located face-to-face synchronous collaboration and they support multiple learners to interact simultaneously with a system through visible gestures and actions ([Bruun et al., 2017](#); [Dillenbourg and Evans, 2011](#); [Evans and Rick, 2014](#)). The combination of social and physical characteristics of tabletops combined with the challenges of supporting productive group dynamics in collaborative learning also pertain to many other emerging mixed-reality platforms. Platforms that provide similar affordances (i.e. support for simultaneous group activity including shared inputs) can be used to facilitate collaborative interactions so it is important to understand how particular design strategies, decisions and features create conditions that enable desirable behaviors.

2.1. Interactional processes in CSCL

Collaborative learning is characterized by a ‘mutuality of influence’ among peers ([O’Donnell and Hemlo-Silver, 2013](#), p. 2). Such bidirectional influence is commonly conceptualized as part of a collective convergent development of thinking toward a state of shared understanding (c.f. [Tissenbaum et al., 2017](#)). The interactional processes of meaning-making through which such intersubjectivity can come to occur, and their productive mediation by designed artifacts, is thus a central focus for CSCL ([Stahl and Hakkarainen, to appear](#)). Two interactional processes identified as key contributors to collaborative learning are the giving of explanations and the joint resolution of conflict. Each provides a mechanism for learners to negotiate common ground ([Beers et al., 2007](#)); that is, for learners to work toward a shared understanding of information, beliefs, assumptions and, in the case of sustainability, values ([Clark and Brennan, 1991](#)). The importance of the ongoing coordination efforts, such as explanation-giving and joint resolution of conflict, to generate and sustain communality is also consistent with [Roschelle and Teasley’s](#) seminal definition of collaboration ([Roschelle and Teasley, 1995](#)).

Explanation-giving is core to many foundational models of interactive processes for collaborative learning. For example, a key element in creating effective argumentation is the process of using evidence and reasoning ([Wise and Hsiao, 2019](#)), that is explanation-giving, to justify one’s position ([Clark and Sampson, 2008](#)). Explaining the reasons for one’s claims offers a partner access to how a learner is approaching a situation, the kind of information that is seen as relevant and the assumed values and goals a learner is trying to meet. As a collaborating learner engages in explanation-giving the opportunity arises for their partner (and themselves) to be open to other ways of thinking and perspectives. It is thus invaluable in the quest to negotiate common ground and measures of explanations (or warrants) for claims have been commonly used as indicators of argumentation quality in collaborative learning (e.g. [Campbell et al., 2020](#); [Wise and Hsiao, 2019](#)). Explanation-giving is also central to the notion of transactive discourse in CSCL ([Stahl, 2013](#)) in which a collaborator makes their reasoning visible to their partner and ties it to priors in the conversation. A display of reasoning is considered to include some sort of an evaluation, comparison or causal mechanism to justify a position ([Fiacco and Rosé, 2018](#)). Transactivity has been shown to be associated with learning in teams in naturalistic settings ([Vogel et al., 2016](#)) as well as ones in which it was induced through design ([Wen et al., 2017](#)). The mechanism here posits not only that making one’s thinking visible through explanation-giving can help the learner partner to move closer in understanding, but also that it can lead the explainer to revise their own thinking as well. Thus, while it is optimal for explanation-giving to flow in both directions, even when only one learner provides an explanation, it can help the other and themselves see a new perspective, and play a part in the negotiation of common ground.

In an interactive tabletop type situation, learners' actions (e.g. gestures, interface touches, tangible object movements) can contribute to the giving of an explanation with or without concurrent verbalizations. Verbalizations and gestures focusing on objects may include descriptions or identifications of the objects, but may also serve more substantive roles in the collaborative task such as making a comparison or showing a causal logic. The tabletop system acts as a medium for this joint activity and thus its design may constrain or guide collaboration in various ways (Suthers, 2006; Tissenbaum *et al.*, 2017). Prior work with a tangible tabletop in a mixed-reality environment that prompted students to explain their reasoning observed that even when explanations were quite short, the cumulative effect was one of learning through explaining to each other (Yannier *et al.*, 2013). Explanation-giving, which includes a *why* as well as a *what* in the context of collaboratively solving a task, is a critical interactional process in negotiating common ground. We code and examine instances of the two constructs: *two-way explanations* (involving both learners) and *one-way explanations* (involving a single learner).

Another interactional process that supports the negotiation of common ground is the resolution of conflict: a recognized disagreement about ideas, opinions, goals or values (Beers *et al.*, 2006). Surfacing or creating socio-cognitive conflict is a common strategy in CSCL (Vogel *et al.*, 2017) where various scripts may induce learners to 'identify, discuss and resolve differences of opinion and knowledge' (Weinberger *et al.*, 2013). Conflict offers an important opportunity to negotiate common ground if it is resolved by the learners together (van Boxtel *et al.*, 2000), leading to a recognition of alternative perspectives, updates to personal and shared understandings and the building of more complex and meaningful knowledge structures (Schwarz and Asterhan, 2010). There may also be a benefit for explanation-giving (Woodward *et al.*, 2018) as learners try to convince one another. However, often consensus that is reached quickly and superficially or conflict that is resolved unilaterally by only one learner, misses an opportunity for negotiation and detracts from the establishment of common ground (Weinberger and Fischer, 2006). In mixed-reality environments that support social and/or embodied interaction, such as tabletops, conflict can also be expressed physically, for example by one learner dominating interaction with the table, blocking access to tangible or digital objects or taking actions that negate those taken by another learner (Jamil *et al.*, 2017; Marshall *et al.*, 2009; Woodward *et al.*, 2018).

The second focus of our analysis of children's interaction during the tabletop learning activity is on conflict resolution, since when this occurs jointly is an important contributor to negotiating common ground. We code and examine instances of the two constructs: *bilaterally resolved conflict* (in which learners work through their difference together) and *unilaterally resolved conflict* (where there is a failure to negotiate and one learner takes an un-agreed upon action).

In summary, based on our conceptualization of negotiation processes as critical to successful collaborative learning, our analysis of children's interaction during the learning activity focuses on explanation-giving and conflict. We code and examine instances of a total of four constructs: *two-way explanations* (involving both learners) and *one-way explanations* (involving single learner) as well as *bilaterally resolved conflict* and *unilaterally resolved conflict*. We compare instances of these four constructs both quantitatively and qualitatively between roles/no roles groups (design strategy for positive interdependence) and across groups (design strategy for reflective pauses). For reasons of scope, we do not examine the overlap of explanation-giving and conflict together.

2.2. Designing for positive interdependence

One approach to designing tangible tabletops that can support the negotiation of common ground is to structure positive interdependence into the activity design in using technical as well as physical and social design elements (Antle and Wise, 2013; Dillenbourg and Evans, 2011). Positive interdependence refers to the extent to which group members are dependent on each other for effective action (Johnson and Johnson, 1999). A classic example is the jigsaw script (Dillenbourg and Hong, 2008) where each person is given part of the information or expertise needed to be successful in the task, thus requiring people to work together to be successful. There are a variety of additional CSCL scripts designed to create positive interdependence in different ways, for example, via assignment of roles or designation of tools to particular learners (Järvelä *et al.*, 2004; Vogel *et al.*, to appear). The aim of creating positive interdependence is to encourage learners to work together in ways that require the negotiation of common ground as opposed to working independently, in parallel or in divide-and-conquer mode.

In the context of tangible tabletops Antle and Wise (2013) have suggested that positive interdependence may be achieved through a combination of technical and social system design. Physical objects, such as tangible input objects or networked augmented reality devices, offer particular affordances for creating positive interdependence as they allow for the physical embodiment of distributed control and can tap into social norms around object ownership and use (Speelpenning *et al.*, 2011). Such interdependence can be employed through physical means (e.g. using colors to designate tangible pieces for use by different group members; Dillenbourg and Evans, 2011) or in concert with social interdependence (i.e. tools are distributed in alignment with particular roles or duties). A combination of these strategies is particularly attractive as a way to address the challenge of getting learners to actually adopt the distinct rights and responsibilities of the role they are assigned (Wise *et al.*, 2012). The specifics of how we instantiated a design strategy for positive interdependence in Youtopia is described below in the context of our overall system design.

2.3. Designing for reflective pauses

Previous research with tangible tabletops has pointed to the need for design strategies that enable opportunities for joint reflection within collaborative interaction with tabletops (Antle, 2014; Okerlund *et al.*, 2016; Price *et al.*, 2010). This has been described as the need for both diving-in, through direct interaction with learning materials and space for stepping-out to co-construct deeper meanings collaboratively (Ackermann, 1996). In the context of tangible tabletops, Antle and Wise (2013) have suggested using the temporal and spatial properties of interaction to slow down actions and provide opportunities that trigger reflection. For example, in a fast-paced touch tabletop sustainability activity *world events* can be used to spark joint reflection; these are system events that pause interaction, take over the display and provide status information about the health of the world and in doing so provide a reason for students to reflect before they continue in their task (Antle, 2014). Based on this prior work, we suggest that *reflective pauses* are an important design strategy to ensure that throughout the activity students have breaks in interaction accompanied by reasons to reflect which may lead to rich negotiation-based dialogue. The specifics of how we instantiated design strategies for reflective pauses in Youtopia are described below in the context of our overall system design.

3. RESEARCH CONTEXT: YOUTOPIA

Youtopia is a collaborative tangible and multi-touch tabletop simulation that helps children learn about sustainable land-use planning. It was designed for pairs of elementary school learners and aligned with the environmental and sustainability topics in the Prescribed Learning Outcomes (Grade 5) and the National Science Education Standards (K-4) for students in British Columbia, Canada. Key learning goals included the following: recognizing that resources are things that we get from the living and non-living environment to meet the needs and wants of a population and that the supply of many resources is limited; describing how the use of particular resources contribute to meeting human needs and the environmental condition; and analyzing how people can demonstrate stewardship of resources and the environment that balance human and environmental needs. Using Youtopia, learners have the opportunity to design their own world, exploring how different land-use decisions affect the amount of food, housing and energy provided to the population and the impact these decisions have on the level of pollution in the environment. The primary mode of interaction is with land-use stamps, and other stamp tools (described below) (Fig. 2a). Using a simulation enables learners to explore the consequences of their actions in ways that are realistic in terms of sustainable land-use planning and understandable to learners in the target age group (Antle *et al.*, 2011).

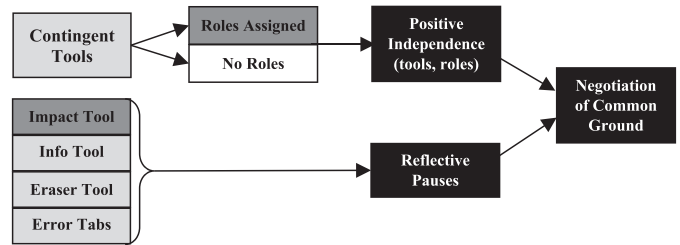


FIGURE 1. Tangible system features to enact design strategies for encouraging the negotiation of common ground; roles are human development and natural resource managers.

3.1. Design strategies, decisions and features

A design strategy is a commitment to an overarching approach to system creation. We then make design decisions in line with that strategy that result in specific system features. These features offer affordances for and constraints on interaction (with the tabletop system), which in turn create, shape and bind opportunities for collaborative learning interactions with other learners. We implemented two primary design strategies focused on support for collaborative learning: (i) positive interdependence and (ii) reflective pauses (see Fig. 1). We also followed general tangible design guidelines for supporting collaborative learning on tabletops (e.g. Antle, 2014), such as providing multiple ways of accessing and interacting with the tabletop (Olson *et al.*, 2010), and general recommendations for collaborative learning about value-laden topics, such as using value-neutral language, removing explicit end goals and enabling bi-directional exploration of the task (Antle *et al.*, 2014a, 2014b; Antle, 2014).

Our approach to designing for positive interdependence involved using a combination of social, physical and technical design elements. We set up a situation for positive interdependence by first creating a technical system involving tightly coupled (or contingent) inputs in the form of a set of tangible input tools. Tangible input tools provide access points that are sequences of inputs that must be taken in order to create a successful system response. Land uses (either natural resource or human development) are designated using a tangible stamp tool for a particular land-use type. Contingent tools are color coded by land-use type to help learners understand which stamps work together (e.g. Fig. 2b). To create shelter, food or energy land uses, at least one natural resource and one human development stamp for that land use must be used. For example, to create shelter, a learner must use the lumber stamp (natural resource) to designate trees to harvest before they can use the housing stamp (human development) to place any type of shelter on grassland. The goal of contingent tools was two-fold. First, it aimed to encourage learners to explore the relationships between different kinds of land-use activities (e.g. harvesting trees into lumber, which is then used to build housing, and which reduces forested areas available

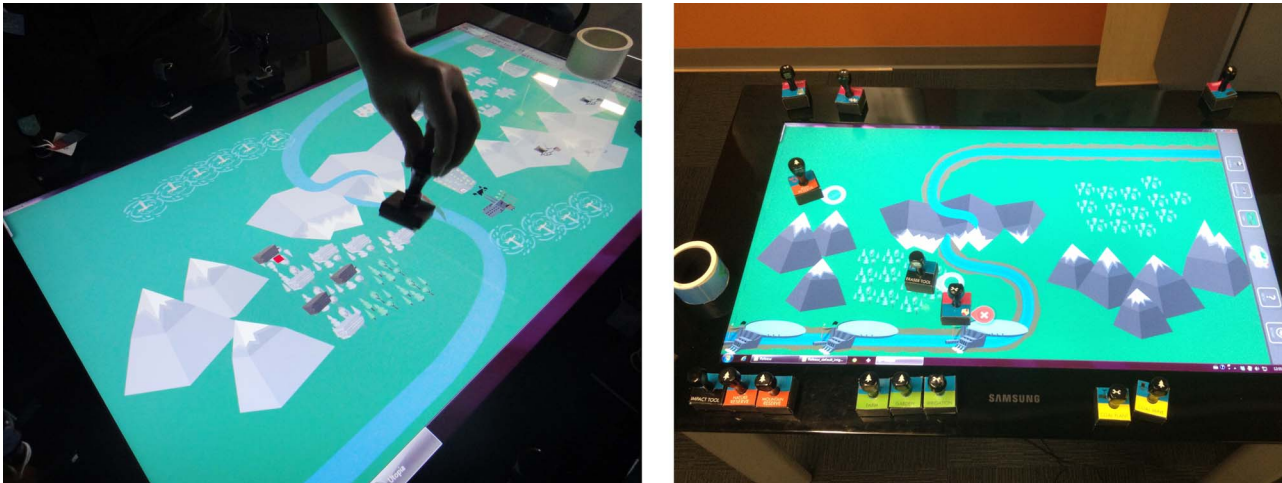


FIGURE 2. Youtopia (a) stamping to designate a land use and (b) colored tags identify groups of contingent (related) stamps to create shelter, food and energy.

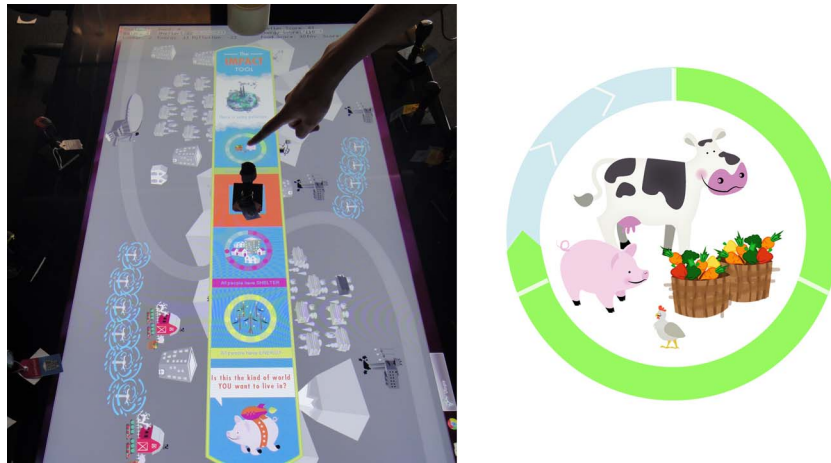


FIGURE 3. Youtopia (a) impact tool and world state overlay and (b) food impact ring.

for reserves). Second, the technological dependencies between the tools were intended to encourage positive interdependence among learners by requiring sequences of multiple inputs to create system responses. With only the contingent (technical) tool design, individual learners could feasibly enact a sequence on their own as well as with their partner. In order to strengthen our design for positive interdependence we added physical and social design elements to our system to support the enactment of roles. We marked the natural resources and human development tangible stamps with corresponding icons: a tree or wrench (physical design). This allowed us to use physical representations to layer social practices on top of the contingent tools by assigning learners in each pair to the role of a natural resource manager or human development manager and give them their subset of marked stamps (social design) (Fig. 1, top). While actual tool use is determined by the

learners, prior work has shown social practices around object ownership often inhibit learners from taking tangible tools that were assigned to their partner (Fan *et al.*, 2014; Speelpenning *et al.*, 2011).

Four system features were designed with the goal of creating opportunities for *reflective pauses*, in which interaction with the technology is slowed to make room for reflection and discussion (Fig. 1, bottom). The first was the *impact tool*, a shared stamp, which enabled either learner to stop interaction and trigger an overlay status of the current world state (with respect to levels of shelter, food, energy and pollution) (Fig. 3). Learners could interact with the overlay display using touch to reveal the interrelations between the world's levels and the particular land uses in place. The second feature was the *information tool*, a ring into which any land-use stamp could be placed to stop system interaction and display the description,

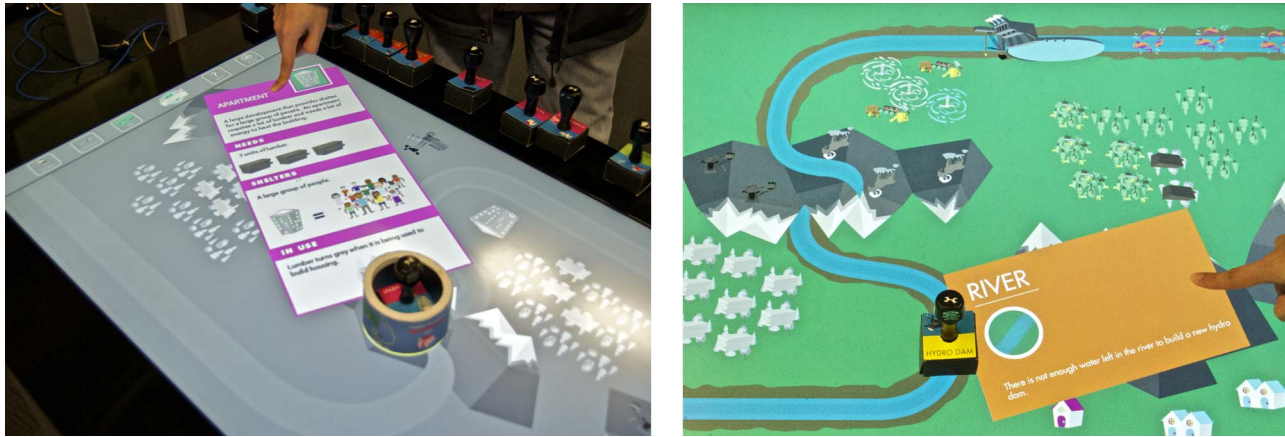


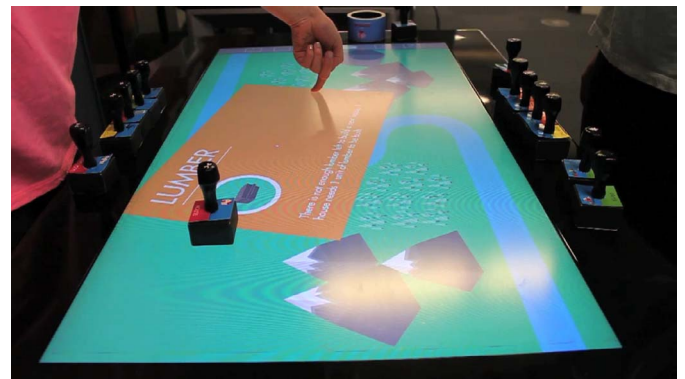
FIGURE 4. Youtopia (a) information tool card and (b) land-use error tab.

productivity, costs and benefits for the land use on a rotatable information card (Fig. 4a). The third feature was an *eraser tool*, a shared stamp, which could be stamped on top of land uses to undo them. The intent of this feature was to lower the barrier to try out actions and discuss their consequences; it also prevented one learner from permanently committing the pair to an action. While the eraser tool did not explicitly stop system interaction, the possibility to undo any action created the potential for an implicit pause after actions were taken to consider if they should be kept or undone. The fourth feature was *error tabs*, which were triggered when land-use stamps were placed in invalid locations (e.g. house in a river). The tabs paused interaction and if the learner touched the color-coded tab then another form of digital card (Fig. 4b) provided learners with information on why the location was incorrect, offering another opportunity to pause and reflect.

3.2. Usage scenario

A typical usage scenario begins with a pair of learners choosing one of four digital maps of an undeveloped valley with different types of terrain: mountains, grasslands, forest and a river. The primary method of interaction with the tabletop is through the land-use stamps, which have predefined relationships to each other and to the terrain designed to reflect real-world relations (Table 1). For example, a farm can only be built on grasslands (not on a mountain) and requires irrigation connecting it to a water source (the river). Thus, as described above, different inputs to Youtopia are contingent and learners can learn about these relationships through the information tool and the error tabs (Fig. 4). When a learner stamps a ‘legal’ land use (in an allowed location; required resources are met), a digital version of the land-use picture on the stamp appears on the map and any required resources it uses are grayed out. Learners can use the impact stamp to assess the state of their world in terms of what proportion of the population has shelter, food and energy,

as well as how polluted the world is. Learners can touch the shelter, food, energy or pollution rings to see the associated land uses light up on the map (Fig. 3). On the impact overlay the pig asks ‘Is this a world you want to live in?’ with the goal of eliciting discussion. Youtopia was implemented on a Microsoft PixelSense digital tabletop. Usability testing to ensure basic standards were met was conducted prior to running the study. A short video of Youtopia’s functionality can be viewed through link at Video 1.



VIDEO 1. Functionality of Youtopia system tabletop [Go to <https://vimeo.com/376547547>].

4. RESEARCH DESIGN AND QUESTIONS

In this paper we report on our evaluation of the effects of two different levels of positive interdependence (contingent tools only and also assigning learners roles and physically marked associated controls) and the four reflective pause features (info tool, impact tool, eraser tool, error tabs) on collaborative activity. We used an explanatory mixed methods approach (Creswell and Clark, 2011) with an experimental manipulation

TABLE 1. Types of land-use stamps.

Area of human need	Natural resource stamps		Human development stamps
Food (green labels)	Garden, farm	←	Irrigation
Shelter (pink labels)	Harvest lumber	→	Houses, town houses, apartments
Energy (yellow labels) ^a	Coal mine	→	Coal plant, hydro plant
Environment (orange labels) ^b	Forest, river and mountain reserves		

Arrows indicate which land uses create resources required for other land uses.

^aEnergy land uses increase the pollution in the world to different extents.

^bEnvironment land uses reduce the pollution in the world to different extents.

of the level of positive interdependence (roles/no roles) in which the initial quantitative analysis of the data identified the relevant video segments for subsequent qualitative analysis (Paulus and Wise, 2019). We examined the effects of reflective pauses on both conditions, as prior work has shown that it is important as a means to create opportunities for reflection and dialogue-based negotiation. The study took place in an authentic school environment, addressing critiques that interactive tabletop research has been overly focused on tool development rather than in vivo studies of collaborative learning (Higgins *et al.*, 2011).

Phase 1 of the study used a quantitative analysis of the data to examine and compare collaborative processes and understand the impact of our approach to supporting positive interdependence (via roles) on these processes. Two research questions probed the *process* of learners' collaboration along three dimensions. These were the most direct measure of the effects of our design strategies on collaboration, thus our primary area of investigation.

RQ1: To what extent do learners using the Youtopia tangible tabletop sustainability simulation engage in the following collaborative processes?

1. Working together
2. One-way or two-way explanations
3. Resolving conflicts unilaterally (one-way) or bilaterally (two-way)

RQ2: Does assigning learners roles with associated tangible controls in Youtopia increase the extent to which learners engage in these processes?

We also asked two research questions that examined the *outcomes* of learners' collaboration along two dimensions. This was an important, but more distal measure of the impact of our design strategies on collaboration, since multiple factors can impact learning outcomes.

RQ3: To what extent do learners who have used Youtopia display evidence of the following learning outcomes?

1. Understand the complexity of making land-use decisions
2. Value land-use decisions that balance meeting human and natural needs

RQ4: Does assigning learners roles with associated tangible controls in Youtopia increase the extent to which they display evidence of these outcomes?

Phase 2 of the study used a qualitative analysis of the explanation and conflict events identified in the quantitative analysis to better understand the nature of the interactional processes that occurred and the relationship of these processes to design features.

RQ5: How were specific tools/tool features in Youtopia taken up by learners as part of collaborative processes P1, P2 and P3 (see above)?

RQ6: How did assigning learners roles with associated tangible controls impact the ways specific tools/tool features in Youtopia were taken up by learners as part of collaborative processes P1, P2 and P3 (see above)?

5. OVERALL METHODS

5.1. Participants and learning environment

Forty fifth grade learners (age: 10–11 years; 18 boys, 22 girls) from two classrooms participated in the study in pairs ($N = 20$) assigned by the teachers to match learners based on three criteria: (i) learners work well together; (ii) learners of high ability are distributed across pairs; and (iii) pairs do not have one individual who is verbally dominant over the other. In addition, teachers were asked to make mixed-gender pairings; however, the class gender ratio necessitated one girl–girl pair in each class. Pairs were randomly assigned (by the researchers) to the roles or no-roles condition, with the restriction of equal representation in each condition across the two classes. Learners were mostly regular users of technology, though there were some exceptions. Due to the culture of the classrooms (and overall school) all learners had extensive prior experience collaborating. In addition, all learners had participated in a class unit on sustainability issues four months earlier, thus prior knowledge on the topic was generally high. Youtopia was introduced as a review of the sustainability unit in which learners would have the opportunity to create a world they would want to live in then share and explain it with the class. Because collaborative activity was our focus (and we expected

learning partners to influence each other) pairs of learners were taken as the unit of analysis.

5.2. Data collection

The primary source of data was *video*. Two installations of Youtopia (tabletop system, tangible objects and associated software) were set up apart from the regular classroom to create a distraction-free environment. Each room was equipped with a high-definition digital video camera capturing a landscape view of the learners (and an oblique view of the tabletop). Videos of 20 sessions of approximately a half-hour each were collected.

Data was collected using a *questionnaire* for learners. At the end of their time using Youtopia, learners were given a closed-ended questionnaire that was delivered verbally and audio recorded. The questionnaire asked for the following: demographic information (age and gender); the frequency with which they used various technologies at home (two questions); their self-reports of the process of working and talking with their partner (four questions); and what they learned about making land-use decisions (four questions). Full question text is included in the results section. For each question, learners indicated whether a statement was true/important/difficult on a five-point scale ranging from ‘not at all’ to ‘very.’

Data was also collected through *teacher evaluations* of final world presentations.

After all learners had completed their Youtopia sessions, each pair presented a printed-out version of their final world map and impact display to the rest of their class explaining:

- The world they created, the rationale for their choices and the trade-offs that were made
- Why they did or did not want to live the world they created

They were also asked to reflect on the following:

- The benefits of working together
- The challenges of working together
- If the world they created reflected what both members of the pair thought was important in balancing human and natural needs

Each classroom teacher evaluated whether learners met, approached or did not meet expectations on each of these five elements using a five-point scale (5 is high). However, in practice the range of this scale was severely restricted as teachers never assigned a score of ‘1’ or ‘2’ for any of the criteria and only assigned a ‘3’ on rare occasions.

5.3. Procedure

Three research team members administered each session of Youtopia; classroom teachers were not present. Pairs were told

they would have up to 25 minutes to engage in the activity. The facilitator began by introducing the learners to Youtopia and showing them the basic tutorial of system functionality. Learners were then invited to use Youtopia to create a ‘world they would want to live in’ that they would later share with the rest of their class and teacher. Specifically, they were told to work together to make shelter, food, energy and nature reserves and that they could change and rebuild their world until they were happy with it. No instructions were given as to what the created world should look like.

In the roles condition, one learner was assigned to be the ‘natural resources manager’ and given all the ‘tree’ stamps associated with this role (lumber, garden, farm, coal mine, forest reserve, river reserve, mountain reserve); the other learner was assigned to be the ‘human development manager’ and given the ‘wrench’ stamps associated with this role (irrigation, house, townhouse, apartment, coal plant, hydro dam). Roles were assigned randomly to learners by the researchers, balancing across gender in the overall sample. Tools not associated with a particular role (impact tool, information tool, eraser tool) were placed at the end of table between the learners. In the no-roles condition the pair was simply given access to all of the stamps/tools placed at the end of the table equidistant between them and grouped by color related to particular human needs (Table 1 and Fig. 2b). Youtopia activity sessions were spread across the course of a week.

6. PHASE 1: QUANTITATIVE ANALYSIS AND RESULTS

6.1. Data coding

Video data was coded to index two aspects of learners’ collaborative processes: first, the degree and type of their *explanations* (*one-way/two-way*) about the sustainability domain; and second, the degree of *conflict* they had around the sustainability domain and how it was resolved (*unilaterally/bilaterally*). We had initially also planned to code a more general collaboration measure of ‘working together’ (time in which both learners worked on a common element of the task); however, since all pairs in the study were seen to work together all the time, this measure was discarded and working together was indexed simply by the total time the learners engaged with Youtopia.

Explanation Events were periods of Youtopia use in which one or both learners explained their thinking or reasoning related to decisions about what resources and developments to use in the activity, and in which they inferred or made mention of one or more values in that explanation. For example ‘Let’s build houses, not apartments - they use less lumber so we can make more forest reserves’ would be coded as a one-way explanation. However, the statement, ‘I think we should have houses not trees’ would not be coded as an explanation event because it lacks a ‘why’ or ‘because’ reason in addition to the ‘what.’ While individually such sentences

TABLE 2. Working together variables by condition.

	No roles ($N = 10$)	Roles ($N = 9$)	t	P^b
'I worked a lot with my partner while I was doing the activity.' ^a	4.35 (0.41)	4.28 (0.36)	-0.40	(0.336)
'I worked mostly on my own while I was doing the activity.' ^a	1.48 (0.45)	1.56 (0.52)	0.36	(0.361)
Duration of system use (min)	21.85 (4.55)	24.99 (3.43)	1.69	0.055
Challenges of working together discussed in presentation (teacher scored)	4.50 (0.85)	4.11 (1.1)	-0.88	(0.197)
Benefits of working together discussed in presentation (teacher scored)	5.00 (0.00)	4.33 (1.0)	-2.00	(0.040)

^aSurvey scale ran 1–5; higher numbers indicate greater level of agreement.

^bP values given are for one-tailed tests; parentheses indicate if difference was not in predicted direction.

may not seem as in-depth as educators might aspire for, the inclusion of (any) justification is noteworthy for this population (ten year olds) and the accumulation of such statements over time could position reasoned, values-based decision-making centrally in their collaborative dialogue. Occasions in which only one learner explained their thinking or reasoning were coded as *one-way explanations*, while episodes in which both learners explained their thinking were coded as *two-way explanations*.

Unilaterally/Bilaterally Resolved Conflict Events were periods of Youtopia use in which learners expressed verbal and/or physical disagreement with the other's actions or utterances related to the sustainability domain. For example, if one learner started to stamp a Garden and the other said 'No, let's make a Farm,' or one learner wordlessly grabbed another's stamp it would be coded as conflict. However, if one learner presented options and the other decided, (e.g. 'We could make a Garden or a Farm . . . 'Farm!') it was not considered conflict. Each conflict event was coded for whether it was *unilaterally resolved* (a learner took final action without other's consent) or *bilaterally resolved* (agreement was reached before final action was taken).

Three researchers were involved in coding the video data, marking all *one-way/two-way explanation* and *unilaterally/bilaterally resolved conflict* events of the types described above with both a start and end time. These were used to calculate variables for both the frequency (number of occurrences) and average duration of each kind of event. Because the presence or absence of assigned roles was apparent in the videos, coders were not blind to condition. Coders trained on a practice video prior to actual coding. Inter-rater reliability was calculated using Cohen's kappa based on the overlap of time segments coded permitting a 5-second tolerance at the start and end of events. Thirty percent (six) of the videos were double coded, three at the start of the analysis ($\kappa_{\text{Explanation}} = .63$; $\kappa_{\text{Conflict}} = .81$), and three at the midpoint ($\kappa_{\text{Explanation}} = .65$; $\kappa_{\text{Conflict}} = .92$). All differences in coding were reconciled.

6.2. Results

Youtopia gameplay sessions lasted 14–30 minutes, with an average length of 23 minutes ($SD = 4.4$). There was one outlier

pair (roles condition) with no explanation or conflict events of any kind; video review showed the pair to be quiet and disengaged from the task throughout the session, thus the pair was excluded from further analysis. For the remaining 19 pairs, data is presented by measure first descriptively across the entire sample (RQ1 and RQ3), followed by a comparison across role/no-role conditions (RQ2 and RQ4). For comparisons, due to the small sample size and a clearly identified hypothesized direction of effects, one-tailed tests were used.

P1: Working together.

All pairs reported high levels of working together; no differences were seen between the two conditions (see Table 2). The amount of time actually spent working together (indexed by duration of Youtopia use) was 3-minute longer on average for pairs in the roles condition; however, the difference failed to reach significance. There was no difference in the teachers' evaluation of the degree to which learners discussed the challenges they encountered in working together. However, the evaluation of the degree to which they discussed the benefits of working together in their class presentation was somewhat higher for the no-roles condition; had our hypothesis been in the opposite direction, this result would have been significant.

P2: Explanations (one way/two way).

The total number of explanations per pair ranged between 2 and 19, with an average of 10 per session, accounting for ~5% of learners' total play time. Looking at patterns of explanations across all pairs, on average there was a greater frequency of one-way explanations ($M = 7.26$, $SD = 3.90$) than two-way explanations ($M = 2.95$, $SD = 2.32$) [$t_{18} = 6.31$, $P < .001$]. However, when they occurred, two-way explanations had longer average durations ($M = 10.37$ sec, $SD = 4.37$) than one-way explanations ($M = 4.33$ sec, $SD = 1.09$) [$t_{16} = 5.39$, $P < .001$]. Comparing role and no-role conditions, the number, but not length of one-way explanations was greater for pairs in the roles condition; however, no differences were seen in the number or length of two-way explanations (see Table 3).

P3: Engaging in and resolving conflict.

The data distribution for conflict was heavily skewed and kurtotic due to a substantial number of pairs without any events; thus assumptions of normality were violated and non-parametric tests used. The predicted higher frequency of unilaterally resolved conflict for the no-roles condition was observed

TABLE 3. Frequency and length of explanations by condition.

	No roles ($N = 10$)	Roles ($N = 9$)	t	P^a
Mean and standard deviation				
One-way explanation				
Frequency (number)	5.80 (2.86)	8.89 (4.40)	1.83	0.042
Average length (sec)	4.35 (1.05)	4.37 (1.12)	0.06	0.957
Two-way explanation				
Frequency (number)	2.60 (2.12)	3.33 (2.60)	0.68	0.254
Average length (sec)	10.89 (5.14) ^b	9.78 (3.58) ^b	0.51	(0.619)

^a P values given are for one-tailed tests; parentheses indicate if the difference was not in the predicted direction.

^b N in this cell was reduced by one, after removing a pair that did not have any two-way explanations.

TABLE 4. Frequency and duration of conflict types by condition.

	No roles ($N = 10$)		Roles ($N = 9$)		Mann–Whitney P (One-tailed)
	Median	Max	Median	Max	
Unilaterally resolved conflict					
Frequency (number)	0.5	4	0	1	0.030
Average duration (sec)	6.67 ^a	12.5	4.4 ^b	4.4	-
Bilaterally resolved conflict					
Frequency (number)	1	8	0	3	(0.029)
Average duration (sec)	9.32 ^c	22.7	32.73 ^d	50.5	0.031

^a $N = 5$.

^b $N = 1$.

^c $N = 8$.

^d $N = 4$.

Mann–Whitney test was not run if combined N across cells < 10 .

(see Table 4). However, results unexpectedly showed the no-roles condition also had a greater frequency of bilaterally resolved conflict; had our hypothesis been in the opposite direction, the difference would have been significant. When bilaterally resolved conflict did occur for roles pairs, it lasted significantly longer than bilaterally resolved conflict for no-roles pairs. As there was only one instance of unilaterally resolved conflict in all the roles pairs, it was not possible to meaningfully compare duration.

O1: Understanding the complexity of making land-use decisions

Overall learners reported moderate levels of understanding of the complexity of making land-use decisions (Table 5). No differences between conditions were found. The teachers' evaluations of the content of learner presentations was consistently high, with all pairs receiving a 5 on one of the two criteria and only two pairs receiving a 4 instead of 5 on the other, thus no significant differences were found.

O2: Valuing land-use decisions that balance meeting human and natural needs

After playing with Youtopia, all learners reported generally high levels for the value they placed on making land-use

decisions that balance human and natural needs. These values were somewhat higher for the no-roles condition; had our hypothesis been in the opposite direction, this result would have been significant (Table 6). A similar trend was seen in learners' reports of having learned about balancing needs by working with their partner and the teachers' evaluations of learner descriptions of how they balanced what each team member thought was important.

7. PHASE 2: FOLLOW-UP QUALITATIVE ANALYSIS AND FINDINGS

The quantitative analysis revealed significant differences between role and no-role conditions in the frequency of one-way explanations as well as in the frequency of unilaterally resolved conflicts and both frequency and duration of bilaterally resolved conflicts. To examine how and why these differences occurred as well as probe the ways in which our design strategies of positive interdependence and reflective pauses supported explanations and conflict events, we conducted a follow-up qualitative analysis of the video data (Creswell and Clark, 2011). Specifically, we explored the general character

TABLE 5. Understanding complexity of land use variables by condition.

	No roles (<i>N</i> = 10)	Roles (<i>N</i> = 9)	<i>t</i>	<i>P</i> ^b
	Mean and std. dev.			
'Making land use decisions that balance natural and human needs is difficult.' ^a	3.15 (0.58)	2.92 (0.81)	-0.73	(0.239)
'Everyone should have the same idea about the kind of world they want to live in.' ^a	2.70 (0.75)	2.72 (0.51)	0.08	0.470
Clear description of how did/did not want to live in their Youtopias world (teacher scored)	5.00 (0.00)	5.00 (0.00)	-	-
Rationale given for decisions/tradeoffs (teacher scored)	5.00 (0.00)	4.78 (0.44)	-1.51	(0.085)

^aSurvey scale ran 1–5; higher numbers indicate greater level of agreement.

^b*P* values given are for one-tailed tests; parentheses indicate if difference was not in predicted direction

TABLE 6. Mean and standard deviation of valuing balance in land-use variables by condition.

	No roles (<i>N</i> = 10)	Roles (<i>N</i> = 9)	<i>t</i>	<i>P</i> ^b
'Making land use decisions that balance natural and human needs is important.' ^a	4.65 (0.34)	4.36 (0.28)	-2.01	(0.031)
'Working with my partner helped me learn about balancing human and natural needs.' ^a	3.90 (0.81)	3.44 (0.53)	-1.43	(0.085)
Described if world reflected what each member thought was important in balancing human and natural needs (teacher scored)	4.90 (0.32)	4.44 (0.73)	-1.74	(0.055)

^aThe survey scale ran 1–5, with a higher number indicating a greater level of agreement with the statement.

^b*P* values given are for one-tailed tests; parentheses indicate if the difference was not in the predicted direction.

of how each of these interactions were taking place across both conditions (RQ5) as well as the ways they were taking place differentially in the roles and no-roles conditions (RQ6). Our goal was to draw threads of connection between the instantiated design strategies of positive interdependence and reflective pauses and how collaborative processes were enacted in Youtopia. As two-way explanations were relatively few in number and did not differ across conditions, they were not examined. Particular attention was paid to the concerns of video-based data (Derry *et al.*, 2010) in terms of clip selection (using the events identified in the quantitative analysis as the sample) and support for pattern finding (using a combination of transcription and narrative summary). Data analysis was conducted inductively following the constant comparative method (Auerbach and Silverstein, 2003; Gibson and Brown, 2009), an approach in which researchers systematically compare each new unit of data (e.g. a segment of video in which an explanation takes place) with all previous units as well as any commonalities across data units that have already been identified. The goal is to identify themes of meaning, where importance derives not simply from the number of times something occurs, but also its weight and apparent consequence to participants. Standards for rigor in this tradition differ from traditional notions of independent inter-rater reliability and instead refer to credibility (the extent to which findings offer a valid representation of reality) and dependability (the

consistency and repeatability of findings) (Lincoln and Guba, 1985). This study established credibility through triangulation (ensuring data from multiple sources—participants, times, areas of focus—supported each finding) and structural corroboration (checking all possible findings for disconfirming evidence and possible alternative explanations). Dependability was established through the application of a meticulous analysis processes (described below) and keeping an audit trail of all codes and decisions made at each stage in the process.

7.1. Analysis process

The video segments identified for each of the three categories in the original coding were transcribed by a researcher into a text file (Fig. 5). Transcriptions included (i) all verbalizations during the coded time period and two to four turns of talk before and after for context and (ii) indication of the physical actions taking place during/between turns of talk: (a) body position, (b) tool use, (c) gestures, (d) facial expressions and (e) learner location around the table. In addition, the transcriber provided a global overview of each event to provide context for reading the transcript.

Three researchers then individually worked in a sequential manner through the transcripts organized into sets by event-type and condition (e.g. one-way explanations in roles

L1 (f) Human Devel.	L2 (m) Natural Resour.	Verbalizations and Physical Actions Surrounding L1 Explanation in R1@8:39 ¹
X	X	Both L1 and L2 place coal mine in info ring and read, mumbling to themselves.
	X	Oh so maybe it's already run out. That was fast [removes mine stamp and info tool from screen]
X		But we already put one [pointing to mountain area of map] coal mine thingy
	X	Let's try another one [stamps coal mine on mountain]
X		It might pollute a lot though [hovers coal plant stamp tentatively over mountain]
	X	Yea that's true
X		Let's try another reserve [puts coal plant down and erases the coal mine]

FIGURE 5. Sample transcript of a one-way explanation by learner L1 about her reason to stamp coal plant in roles pair R1 at 8 minutes and 39 seconds into the session.

condition)¹ to identify possible themes in the data using the constant comparative method (systematically comparing each new video segment with all previous segments of the same type and condition). Each possible theme found in a subsequent event-type/condition set was taken back for examination in all prior sets. The three researchers discussed all proto-themes by event type and condition, condensing and combining similar ideas. Each potential theme was then subject to individual scrutiny with a search through the transcripts for confirming/disconfirming evidence and any possible alternative explanations. Several themes were discarded for lack of sufficient substantiating evidence or relevance to the focus of the study while others were combined as overlaps were identified. In the end, the final set of consolidated themes with supporting evidence contained six themes related to explanation-giving and three relating to conflict.

7.2. Findings: one-way explanations

The six themes described below and summarized in Table 7 speak to how one-way explanations were initiated by learners using Youtopia, noting distinctions in how this happened with and without the assignment of roles/tools, and any ways the four *reflective pause* tools (i.e. impact, information, eraser tools and error tabs) were used within the context of explanation-giving for both groups.

Explanation Theme 1: Explanations Occurred as Responses to Different Things

One-way explanations in both conditions occurred commonly as a response to the world-state; in the roles condition

explanations also occurred in response to a partner action or comment. In no-roles pairs, one-way explanations were commonly made in response to the state of the world. This was usually prompted by use of the impact tool, which paused interaction, and the feedback this tool provided, which promoted reflection (e.g. ‘So how are we turning out [puts impact tool on screen]. Food is pretty good. I think it is really good because there is no pollution’ L1 in N8@15:58). Learners also gave explanations of their thinking about the world state as depicted on the map (e.g. ‘I don’t like how we took up all the trees but [rubs hands on face] . . . like . . . I think it’s good.’ L1 in N1@18:03). Importantly, the explanation was given in direct response to the world-state information provided by Youtopia (map or impact tool). In **Roles** pairs one-way explanations were made in response to both the state of the world and directly to things the partner did or said (i.e. not the state of the world itself but the action the partner wanted to take on it). This second type of explanation often related to stamp ownership (e.g. ‘Yea, because then most people will have food’ L2 in R6@18:54 responding to their partner, who had the garden stamp but had not yet used it, making a hesitating statement that only ‘maybe’ stamping it was a good idea). Similar explanations occurred even when the action involved the eraser tool, which both learners had access to, indicating a tacit acknowledgement of the ownership of particular land-use decisions (e.g. ‘These ones? [motioning to apartments] maybe we *should* lose some apartments. They’re too cramped up in that area’ L2 in R5@16:19, responding to their partner’s suggestion that they should remove some of the apartments).

Explanation Theme 2: Temporality of Explanations: Backward Versus Forward looking

One-way explanations in both conditions were commonly retrospective reflections looking back on the state of the world; in the roles condition, explanations were also forwards-looking made as part of prospective statements about what should be done to change it. In **No-roles** pairs, one-way explanations were made as retrospective reflections (on the existing state of the world triggered by the impact tool as described above) (e.g. ‘Wait, if you look at our pollution. See now our pollution is fine’ L1 in N3@18:55). At times these also concluded with a call to action about what should be done in response or involved statements of a timeless nature describing what learners valued in the world (e.g. ‘There should be at least many [people who have food]’ L2 in N2@8:57) or ones which described an anticipated future (e.g. ‘Yeah, it will be nice to have some animals’ L2 in N6@3:21). In **Roles** pairs, there was strong presence of one-way explanations given as part of prospective calls-to-action. These occurred both in combination with reflections on the existing world-state triggered by the impact tool (e.g. ‘Oh man, a lot of the water’s gone [looking at the brown river], do you think we need to kill the hydro dam? L1 in R8@12:56’) but also independently, which was not seen for no-roles pairs (e.g. ‘I don’t know about using coal because we don’t want to make it too polluted’ L2 in R3@10:20).

¹ Because there was only one instance of unilateral conflict for the roles condition, no thematic analysis could be performed. Instead, this one incident was examined for the presence/absence of themes found elsewhere.

TABLE 7. Summary of one-way explanation themes.

#	Topic of theme	No roles only	Both groups	Roles only
1	Explanations as responses to things	N/A	Explanations as responses to world state	Explanations as responses to an action or comment made by the partner
2	Temporality of explanations	N/A	Backwards looking (explaining things that have already happened)	Forwards looking (explaining things that will happen in the future if a certain action is taken)
3	Collectivist vs. partner-oriented personal pronouns	N/A	Strong use of 'we' language	'We' language connected with direct references to the partner ('you')
4	Valence of language	N/A	Positive, explaining how world needs have been met	Negative/questioning, explaining how world needs are not yet met
5	Positionality of perspectives	Balanced human or environmental needs, either from start or by end	N/A	From human or environmental perspective the whole time or from both perspectives, then balanced
6	Stepping inside the world	N/A	N/A	Explanations included perspective of the world inhabitants

Explanation Theme 3: Collectivist Versus Partner-Oriented Personal Pronouns Used in Explanations

One-way explanations in both conditions involved strong use of collectivist language ('we'); in the roles condition language connecting this to the learning partner ('you') was also seen. In **No-roles** pairs, one-way explanations commonly involved use of first person plural (e.g. 'Okay so that means we need more trees which is kind of sad' L1 in N1@3:30) though some use of first person singular was also seen (e.g. 'I think it is really good because there is no pollution' L1 in N8@13:05). When employed, use of the first person singular was almost always followed by an opinion verb such as think or feel (as in the example above) and often also connected with a reference to the collective (e.g. 'I feel like we're using up too much of the trees' L2 in N4@9:55). A similar pattern was seen for **Roles** pairs with the addition of notable use of the second person singular ('you') in combination with a reference to the collective (e.g. 'Do you want to try another irrigation to get more food 'cause that's the only way big problem we have?' L2 in R1@25:00).

Explanation Theme 4: Valence of Language Used in Addressing World Needs

One-way explanations in both conditions used positive language to give confirmation of needs being met; in the roles condition explanations were also given in response to unmet needs, either through negating things a partner had said/done or using questions to seek confirmation, agreement or action. In **No-roles** pairs, learners gave one-way explanations about three main aspects of the world (triggered by the impact tool display of world state) largely using positive terms: when the environment was relatively healthy (e.g. 'Okay there's little

pollution. That's way better.' L2 in N1@7:25); when human needs were met (e.g. 'Oh wow... [pointing to full shelter indicator on impact display] ... that's good!' L1 in N7@8:14) and in reference to the balance between the two (e.g. 'Well I want everyone to have energy but then we might have more pollution' L2 in N2@16:42). In a limited number of instances, no-roles learners did use negative terms; but these tended to be tied directly to action-oriented phrases about what should be changed. In contrast, in **Roles** pairs, learners gave their one-way explanations using a variety of neutral, positive and negative statements as well as questions. The presence of explanations with a negative valence was notable; learners often offered an explanation as they opposed something their partner had just said or done that had an undesirable impact on human needs or the environment (e.g. 'But this like pollutes though, remember?' L2 in R2@12:43 responding to their partner stamping a coal plant on the map). Often these opposing statements suggested undoing what the other learner had just done using the eraser tool (e.g. 'Maybe, ugh ... Water brown?' [erases the irrigation they have just stamped in response to their partner's suggestion that they build more gardens and a farm] 'I don't want to do that 'cause then the fish don't have much water.' L2 in R5 15:02). Opposition was also enacted in the form of a question which opened up a space for the partner to share their thoughts in response to the difference in opinion (e.g. 'Why is the garden so far from the houses?' L2 in R2@3:14 [in response to L1 placing an apartment stamp]). Roles pairs also sought confirmation, agreement or action from their partner either directly or indirectly before taking an action (e.g. '[placing impact tool] Not everyone has shelter ... Do you want to take out some parks?' L1 in R8@8:48).

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