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From Participatory to Contributory Simulations: Changing the Game in the Classroom

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ABSTRACT

There is much potential for supporting collaborative learning with interactive computer simulations in formal education and professional training. A number of simulations have been developed for single user and remote interaction. In contrast, our research is concerned with how such learning activities can be designed to fit into co-located large group settings, such as whole classrooms. This paper reports on the iterative design process and two in-the-wild evaluations of the 4Decades game, which was developed for a whole classroom of students to engage with a climate simulation. The system allows students to play and change the rules of the simulation, thereby enabling them to be actively engaged at different levels. The notion of Contributory Simulations is proposed as an instructional model that empowers groups to make informed, critical changes to the underlying scientific model. We discuss how large-group collaboration was supported through constraining an ecology of shared devices and public displays.

Author Keywords

Contributory Simulations; participatory simulations; ubiquitous computing; ambient displays; serious games; collaborative learning; tablets

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces - Interaction styles;

General Terms

Design, Human Factors

INTRODUCTION

Simulations and role-play activities are often used in classroom-based teaching in addition to lectures and discussion. They allow groups of students to think for themselves about a topic by engaging in active problem solving. While younger audiences are often given well-structured problems with pre-defined solutions, higher-level education and professional training courses recognize the need to involve mature students more deeply in the framing of real-world problems and in the critical analysis of these framings.

Examples of real-world problems include complex, global challenges such as climate change. Policy makers in corporations, NGOs and governments need to be trained in thinking about how to solve these by using, on the one hand, scientific and economical models that are based on mathematics and, on the other hand, working out how to deal with uncertainty in numerous ways. Developing practical fluency in using a combination of precision and possibility is critical to this kind of thinking and is key to the success of training courses at this level.

Our research is concerned with how interactive simulations can be designed to be more effective as learning tools for this kind of professional training. In particular, we are interested in how ubiquitous technologies can be used to support simulation-based learning activities that take place during high-profile, multi-day executive training workshops. Initially, we designed 4Decades - an interactive learning tool – in the form of a Participatory Simulation that encourages teams to collaboratively explore a given model alongside discussing and reflecting upon uncertainties. When played by two teams in a real-world training context it was found to promote high levels of collaboration and problem-solving. However, it was identified that it could be improved if the simulation could also enable critical changes to be made to the underlying mathematical model as well as interacting with the visible dimensions at the user interface. A second iteration of the simulation was developed, which we called a contributory simulation, distinguishing it from participatory simulations. The main difference is that our simulation enables teams to explore a hypothetical world and revise it. Decisions were made based on outcomes and interventions, through changing the rules of the simulation. The extent to which having this level of functionality aids thinking collaboratively about complex global problems is discussed. Our findings establish the feasibility of designing contributory simulations using shareable devices and ambient displays and suggest potential for future design and research in this area.

BACKGROUND

Figure 1 shows the different approaches to learning with simulations, that are positioned in relation to one another in terms of the extent to which they include observation versus role-playing and are malleable versus rigid. The majority of early computer simulations that were designed to teach complex topics in science, economics, and so on, were at the fixed and observational end of the continuums. They also ran mainly on single-user desktop applications. These include microworlds that were developed in the 1980s [4] and Scientific Discovery Learning, based on predesigned computational models, in the 1990s [3]. More recently, software tools that allow students to design and test their own systems models, such as NetLogo or StarLogo TNG [9] have been developed. These can be defined as more malleable. Other developments include Massively Multi-player Online Role-Playing Games (MMORPGs) and Serious Games – again largely played on single user desktop machines.

While desktop machines offer the benefits of sophisticated graphical interfaces and powerful computational resources, their affordances for face-to-face interaction in large groups are limited. In many learning contexts where human-human interaction is at the heart of a topic's complexity, for example, in management and political science, educators have instead relied on using paper-based interaction and board games. A limitation of such media is that they can consume large amounts of valuable class time and preparation/evaluation and has meant that many educators have refrained from using simulations in their courses [6].

An alternative approach that has recently been promoted is to provide interlinked technologies in co-located settings that support face-to-face collaborative learning. Roschelle et al. [13], for example, envision new forms of collaborative interaction taking place in the classroom that goes beyond the limitations of paper and desktops. Potential benefits of this form of real-time collaboration include rapid information sharing within the whole class of students and the teacher's ability to monitor and mediate interaction. To enable this, one idea is to provide students with a network of tablet computers. AlAgha [1], for example, recently proposed an extensive architecture for classroom collaboration based on multiple networked interactive tabletops. Another benefit of having a heterogeneous mix of devices is that they can provide Multiple Linked Representations (MLR) that can support peer collaboration as well as individual agency [11]. Moher [12] used tablet devices combined with low-tech ambient displays. His approach - Embedded Phenomena - supported long-term installations for scientific discovery learning in middle-school classrooms. A set of devices were shared by the students in a classroom and used as observation points to collaboratively collect data about simulated processes. The Embedded Phenomena approach aims to help groups of students become a community of authentic scientific practitioners.

Another approach that emphasizes role-playing as a key component is Participatory Simulations [2,16]. These allow learners to explore a model from the perspective of virtual elements within the simulation. Ubiquitous technologies have been used to immerse large, co-located groups of learners in shared, interactive computer simulations. While such embodied learning experiences with complex systems can be engaging and motivating, it has been suggested that Participatory Simulations may be best suited for illustrating the basic idea of a topic, rather than a detailed account [2]. Depending on the case, this may be enough to satisfy a particular goal, e.g. to trigger a discussion about a specific perspective on the topic, which may then feed into other forms of classroom instruction [14].

Scientific Discovery Learning [3] is the instructional paradigm which Embedded Phenomena inherit from Participatory Simulations. Learners are presented with predesigned models and predesigned ways of interacting with them or observing their autonomous progression over time. In the context of entertainment oriented simulations of urban planning and biology, Turkle [15] warns that certain ways of interacting with predefined simulations can result in superficial understanding or factually wrong conclusions about the topic, particularly when the underlying models are not revealed to learners. This call for transparency is in-line with Jonassen's [8] distinction between the black box approach typically taken in microworlds (which Participatory Simulations are a form of [2]) and the glass box approach where the underlying models are explicated and can potentially be modified by learners. Wilensky and Reisman [17] describe such a glass box approach to teaching biological phenomena through scientific modeling. Their approach allows individual students to reflect on emergent properties of complex systems (e.g. the dynamics of predator-prey populations) by manipulating models of local elements (e.g., the behavior of individual animals).

The goal of our research is to extend this approach by combining large-group role-play and malleable models, to enable groups to change and reflect upon aspects of the underlying model in relation to a shared experience of playing the simulation.
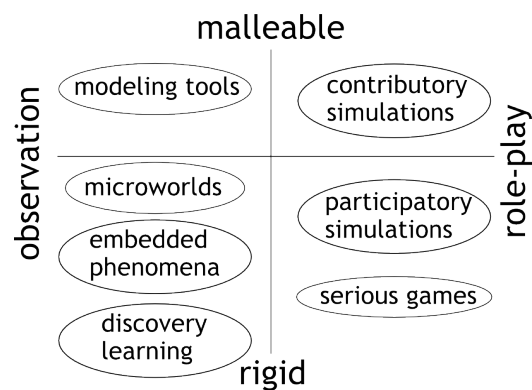

Figure 1: Related approaches to learning with simulations

METHOD

The aim of our research is to explore how interactive simulations, using ubiquitous technologies, can be designed to support collaborative learning in large-group professional training workshops. In particular, we are interested in enabling large groups of students who are immersed in professional training to put into practice what they are learning about a complex topic in lectures over an intensive period of 2–3 days. The objective is to enable them to think creatively and reflectively and to explicitly discuss with each other the rationale for making decisions to solve given problems in a domain.

Towards this goal, 4Decades was designed and evaluated in a series of management courses on sustainable business leadership. To begin, we developed a participatory simulation that would encourage role-playing. We describe the real-world setting before elaborating on the initial design. A second iteration extended the simulation to enable the students to interact and change the underlying model, itself. The idea behind this form of contributory simulation was to enable deeper exploration of the domain by allowing the participants to change the rules and dimensions underlying the model, which in turn, can have an impact on the consequences of their subsequent decisions. Participants can thus experience the domain from the perspective of decision-makers as well as from the perspective of scientists and modeling experts who influence decision-making directly or indirectly through their interpretations of the world.

Fitting in the real world

Professional training workshops often rely on a combination of formal lectures and active learning components, such as case studies or simulations. Because the topics are often complex and controversial in nature, group discussions are considered an integral means for participants to share their perspectives, reflect on their experiences and in so doing support collaborative learning. Discussions also allow the workshop facilitators to interact with the whole group in order to monitor learning and to moderate potential tensions and misunderstandings in the group. When simulations and games are integrated into training workshops, discussions are likely to arise within the context of collaborative playing. They can also be extended to take place outside of the simulation in debriefing sessions [5]. The benefit of having multiple levels of discussion throughout the training sessions is that it provides more opportunities for the students to step in and out and reflect on possible solutions, trade-offs and issues. Figure 2 illustrates how we proposed the simulation game being integrated with lectures and discussions and how the different stages contributed to each other. It is cyclical in nature, showing how subsequent cycles of the game and discussions can be augmented with ad-hoc lectures.

The setting

The 4Decades simulation was designed for deployment in a series of international executive training workshops on sustainable business leadership run by the University of Cambridge. The aim of these workshops is to bring together large groups (typically 25-30) of mid to high-level managers from different professional and cultural backgrounds in order to increase their practical understanding of sustainability leadership. The overarching goal is to enable participants to help their organizations achieve better ways of addressing global problems. Lectures, case studies and simulations have been designed to provide applicable knowledge and foster collaborative leadership skills. Much emphasis is placed on illustrating the interrelation between local policy making and complex global problems, such as climate change.

Climate politics are of direct relevance to the agendas of the participants on the course. As a result of the instructional design being constantly evaluated and refined, the workshop organizers have learned to value the integration of active learning experiences that allow participants to put into practice some of the theoretical knowledge learned in class. Previous deployments of off-the-shelf paper-based simulations and board games had not been satisfactory for these workshops, due to lack of scientific accuracy and/or excessive time cost. The workshop organizers value computer simulations in principle for their power to let participants rapidly explore scientific models that are relevant to their courses. However, they hesitated to deploy off-the-shelf desktop packages, arguing that the single-user orientation and lack of the affordances for face-to-face communication conflicted with the goal of their workshop – which is to provide socially rich, co-located activities for collaborative learning. They asked us to develop a custom-built experience that could support co-located groups of participants learning together and solving problems that were more related to their course material. To this end, we decided to develop a simulation that could run on inter-connected tablets that pairs or small groups could interact with together and use to spark multiple discussions.
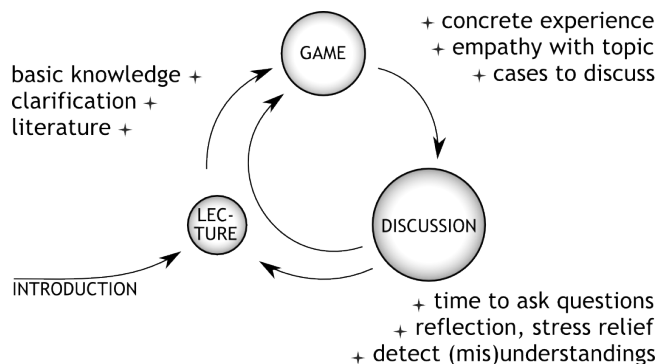

Figure 2: Our proposed pedagogical approach where lectures provide the fundamental knowledge required to play the game
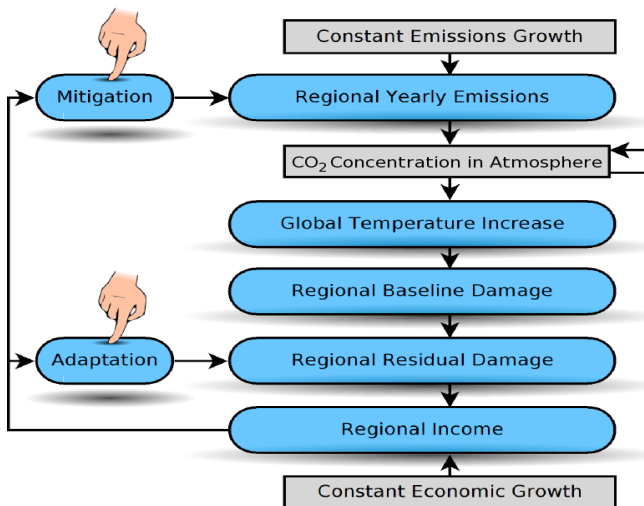
Figure 3: Flow diagram of the economic model. The rounded boxes are variables that users can see.
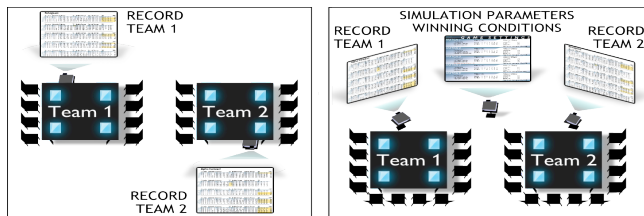

Figure 4: Room layout in version 1 (left) and version 2 (right). Each team shares 4 tablets on a large table and an ambient display. In version 2 there is an additional ambient display.

Figure 5: User interface on each tablet. Information is clearly structured in rows and columns. The lower half shows a forecast to the next round. Four large buttons in the center.

Figure 6: Section of a team's ambient display after 2 matches. Each row represents a round. The full image would show two more columns for residual damage and income to the right.

The scientific model

A number of meetings with the organizers were carried out to understand fully the topic of climate change and the problem-solving activities planned for the participants. Our aim, in agreement with the organizers, was to create a socially engaging activity that would enable the participants to play with a scientific or economic model. The activity was expected to address a number of learning goals: to give participants concrete experience with concepts and numbers that are central to the workshop curriculum; to highlight some of the challenges surrounding decision-making under complexity and uncertainty and to provoke a critical discussion about the simulated topic. It was agreed that the simulation should challenge participants to address the question: *What will be the cost of anthropogenic climate change and how should policy makers balance investments between greenhouse gas mitigation, adaptation to climate change and residual repairs within the next 40 years?* The topic was chosen because of its key relevance to both the workshop curriculum as well as participants' professional situations as policy makers in international organizations. A simple economic model (see Figure 3) was designed, intended to enable participants, in the role of governments, to control spendings in terms of CO_2 mitigation and adaptation to global climate change effects. On the one hand, both mitigation and adaptation cost money. On the other hand, both have the potential to save (more) money indirectly by reducing climate-related damage in different ways. Balancing investments over repeated cycles (decades) becomes a challenge when the goal is to maximize income. By providing participants with multiple copies of this model – which were termed *regions*, in order to avoid comparison with real countries – and linking the regions with a shared global temperature, the climate-economic situation of several governments on one planet is approximated. The model was set so that mitigation spending benefits the whole planet, whereas adaptation spending only benefits a single region that spends the money. This set of rules gives rise to a socially complex 'tragedy of the commons' situation that it was hoped would encourage collaboration within teams.

In order to ensure equitable playing conditions within teams, all regions were defined as being equal in size. The facts and numbers used in the model were based on a collation of recent economic and scientific literature, complemented with approximations where necessary. A more in-depth description of the design rationale can be found in [10].

In order to structure the task of exploring the model, it was decided that two teams would play, each controlling a separate planet (or alternative realities of the same planet). A game was devised of four rounds in which each region decides on their mitigation and adaptation spending. Each team tries to achieve the highest income for their planet after four rounds of the game, proceeding in decades from 2010.

The collaborative simulation interface
It was decided that the interface should be simple and immediately accessible by all participants. This was in part, because there was little time to train the students to learn a new system as the workshops were run on a tight schedule. To begin, we considered using multi-touch tabletops to support interaction with the simulation. However, a limitation of tabletops is they can only support small group sizes (5–6). This would have required several such surfaces to be placed in a room in order to involve the whole group of 30 participants. The cost and logistics of this possible design was a major obstacle. Moreover, multiple tabletops would have fragmented the class into small groups working with little awareness of the others, whereas our goal was to have two large teams competing with one another, being aware of how each other was faring.

Our solution was to use a network of eight shareable tablet devices that supported the same simulation in real time, four for each team. Figure 4 shows the eight tablet devices distributed on two large square tables, with each table representing one of two competing planets and the four tablets per table representing the *regions* on the planets. To show the record of each team's previous decisions and outcomes, a large shared ambient display was assigned to each team. The results of each round were updated after each round. The data displayed was designed to enable the two teams to reflect on their decision-making; to infer how the model worked and to draw conclusions about improving their collaboration and performance in the game while seeing what the other team had chosen to do.

Constraining interfaces to encourage collaboration
A number of constraints on awareness, control and the availability of information [18] were used with the goal of increasing collaboration. These decisions mainly concerned the user interfaces on the individual tablets and the way the network of tablets was controlled. As Figure 5 shows, the user interface on each tablet was designed to be simple. Only few variables are displayed. Moreover, only two variables can be controlled directly. Four large buttons allow participants to increase and decrease values for mitigation and adaptation spending in coarse steps (only whole numbers). In response to a participant pressing a button, the lower half of the screen shows a forecast of what the region's state would be in the next game round if the chosen values were kept.

The forecast was placed below the four manipulation buttons, so that participants could see the values change directly. The rationale was that this would incentivize them to remove their hands immediately after touching it, thus freeing the screen for other collaborators to use. A deliberate delay of one second was imposed on the responsiveness of the buttons, in order to slow down the exploration process, such that other participants could follow the changes more easily. While the forecast allows participants to quickly try out possible investment decisions and evaluate predicted outcomes, its scope was deliberately limited to one local region (as opposed to the whole team/planet) and only one round of the game. Acting strategically on a global and/or long-term level, therefore, requires participants to collaborate on a larger scale. For example, it was expected that participants would be encouraged to coordinate their strategic ideas with other team members across the table or to use the team's shared ambient display.

Additional constraints on interaction were imposed through external control of the networked tablets. In particular, the facilitator controlled the timing of the game rounds. Between game rounds, the tablets turned into a non-interactive state, to make it easier for the facilitator to draw attention to salient aspects or to moderate discussions.

STUDY 1: PARTICIPATORY SIMULATION
A series of lab tests were run with small groups of participants to ensure the simulation was robust, understandable, challenging and engaging. Feedback was received on the usability of the technological set-up and the game mechanics. The first deployment of 4Decades was during a four-day workshop at a conference center. In order to provide an opportunity for participants to put into practice the theoretical knowledge from the first two days, a hands-on session was scheduled at the end of day two after a series of lectures on climate science and economics. A session was scheduled to last for 90 minutes, comprising a brief introduction to the simulation, four matches of playing the game and a final debriefing discussion.

In order to allow enough time for setting up the technology on site, the session took place in a separate meeting room which was not used for other activities. Participants were initially handed badges indicating the team they belonged to. As they entered the room, the facilitator showed each team their table, asking half the participants to sit in pairs at the tablets and the other half to gather around the table. It was explained that the roles within the team would be swapped after each of the four matches. The facilitator further explained what the tables and tablets represented, the objective of the game and the numbers and buttons on the interface. Five minutes later the group was ready to play a brief practice match during which the facilitator explained how the elements on a team's ambient displays showed their decisions on the left, the outcomes of the decisions further right, and how after every round of decision making one row of data was added to the display as a record. The facilitator also encouraged participants to help themselves to the prepared pens and blank paper sheets and some printed tables of mitigation cost and adaptation efficiency. Since all the technical terms used in the simulation had been covered in prior lectures, participants were ready to play without any further introduction to the topic. The game lasted for 55 minutes and the subsequent debriefing discussion was concluded after 10 minutes when nobody had any further comments.

Figure 7: Sharing tablets in pairs. Partners tended to keep their hands close to the devices, always ready to point and press buttons.

The aim of the first trial was to investigate how participants used the tablets and ambient displays, and how engaging and useful they found the activity. We were also interested in whether the game would trigger a critical discussion based on an understanding of the model and reflection on what was taught in the prior lectures.

Evaluation

Since this was the first deployment of the prototype in the wild, an exploratory approach to evaluation was taken with the aim of collecting a wide range of potentially relevant data while also keeping the observation as unobtrusive as possible. A questionnaire was provided by the workshop organizers at the end of the session. An additional web survey was sent to participants after a delay of several months to elicit long lasting impressions.

Field notes were also taken by two researchers in the room, video was captured from all 4 corners of the room and a small microphone on each table was used to capture audio. Screen shots of the ambient displays were used to analyze team strategies.

Use of devices and displays

Our observations of the teams revealed that as soon as the facilitator initiated the first round, all eyes were on the tablet devices. Seated pairs were immediately engrossed in pressing the buttons and watching the numbers change, thinking aloud together while exploring the interface. Standing participants watched the tablets over their team-mates' shoulders. It appeared that the tablet interfaces were immediately accessible and understood by participants. Sharing the tablets worked seamlessly as tablets were kept centered between pairs and participants naturally drew their hands back after pressing buttons, thus effectively releasing control and freeing the screen for others to peek in (Figure 7). Standing participants seemed to benefit from this affordance as they often used their mobility to peek into several tablets to assist collaboration from more of a bird's eye view. Standing participants were also engaged in dialogue with pairs. They contributed mostly in verbal form, e.g. suggesting theories and strategies, directing attention to other regions or data on the ambient displays, but rarely touching the tablets directly. No difficulties regarding the usability of the tablets and ambient displays were observed or mentioned in the debriefing discussion. Swapping roles between sitting and standing participants after each match allowed every participant to use the tablet interface.

After each round, the decisions of each region and the respective outcomes were added to the shared record on each team's ambient display as an additional row (see Figure 6) and thereafter, many participants were eager to see their team's results following each round, appearing on the screen. Comparing a team's results immediately with the other team's results was the main use of the ambient displays in the early matches. As new data was added to the tables on the ambient displays, the participants became quicker at knowing what to look for, helping them to reflect more readily on the aggregate data and theorize about their implications. Increasing numbers of participants spent time focused on their own team's or the other team's scores, discussing ideas in small sub-groups or pairs. Some of these discussions happened as independent threads outside the main action at the tables. The ambient displays were further used in the debriefing discussion to recall significant moments and support arguments with concrete data. For example, figure 6 shows that the team found consensus on a strategy for match 2, whereas in match 1 different regions had entered different values.

Over the course of the four matches, the extent of collaboration could be seen to gradually increase from controlling the simulation via tablets in pairs, to sub-team tactics, to team strategies and whole-classroom exchange of information. In the first matches, most of the talking occurred between pairs sitting by the tablets, changing the values on the screen, while the others were either watching intently or talking to their closest neighbors. Decisions in the game were made on a local basis without consulting the whole team. Later matches were characterized by efforts to establish a shared awareness of the whole team's situation and a team-wide strategy, as groups realized that local decisions affected the state of the simulation for the whole team. Increasingly, seated participants made eye contact and verbal contact with other seated participants across the table and standing participants started walking between regions, comparing values between devices, making suggestions and engaging in clarifications and arguments.

Minor clarifications were handled in a lightweight fashion among peers, thus allowing the facilitator to stay in the background, casually observing the whole-room interaction and the data on the ambient displays. At the end of each round, when the tablets switched to a non-interactive state and the data was updated on both teams' ambient displays, the overall attention of the teams shifted noticeably from the tables to the whole room. Sometimes the facilitator would use these breaks between the rounds as opportunities to get the attention of the whole class, e.g. to provide additional information, without interrupting the flow of the game.

Participant satisfaction

Participants were engrossed in the activity from the beginning of the game and stayed engaged throughout the 90 minutes session. The whole session was rated on a Likert scale, from 1 to 5, with an average score of 4.1, which is close to the whole course's average rating of 4.23. Out of 20 responses nobody gave the lowest score of 1. Another indication of its success, was receiving several invitations from delegates to deploy 4Decades in their organizations and the workshop organizers asking us to deploy the simulation again in their next workshop.

Supporting reflection and critical discussion

When reflecting on their strategies during the debriefing discussion, participants related their game experience to the roles of real-world policy makers, emphasizing the value of whole-team communication. Two participants from different teams summarized their team's collaboration:

"There was a lot of really good collaborative policy making going on, probably on both teams. Especially after the first [match] everybody started to kind of communicate across the table. And that fairly rapidly got us towards [winning]"

"You think you've made an agreement and then [...] a region changes their opinion [...] you put that to the global level, and you see exactly how that, that same psychology plays out but far worse, with far bigger stakes."

A surprising observation was that, despite the fact that the winning condition was explicitly as 'the planet with the highest global income by 2050', there was an internal dispute in both teams regarding whether income or stabilizing global temperature should be prioritized:

"The money was a driver, but... I think we didn't... erm... we certainly could have made a lot of our decisions based on trying to keep the temperature down."

In the debriefing discussion many nodded in agreement with a participant contrasting the amount of feedback from the simulation with expectations based on prior lectures:

"We were slightly surprised that a bit more spending on mitigation in the early decades didn't deliver a better result [than an adaptation-focused strategy], which is what you'd have thought from what we were hearing and discussing today."

Despite critical discussions about the discrepancy between expected and produced output values, participants' efforts to attribute this discrepancy to specific aspects of the model were rare and imprecise. Instead, it appeared more likely that they perceived the game as a *black box* that delivered certain outputs based on certain inputs and unknown transfer characteristics which were not intended to be known or criticized. This conjecture can be seen as supported by participants' frequent use of words such as 'reward', 'punishment' or 'penalty' when referring to feedback from the game.

In order to address the critical comments made by the participants about the limitations of the underlying model we decided to refine the model and make it possible for the participants to be able to change the underlying rules. These were the mitigation cost function, the function for adaptation efficiency and the winning condition. Our overall aim was to find effective ways of enabling the teams to engage in meaningful design decisions. Given that the interface, the configuration of networked tablets and ambient displays was found to be very usable and highly engaging we chose not to change these.

DESIGN ITERATION

In order to make the model and its underlying assumptions more transparent to participants, it was decided to give groups the ability to be more involved in the design of the simulation. In particular, we looked for ways to enable the groups to create variations of the original simulation that they could immediately evaluate through play.

Our starting point was a thematic analysis of the participants' discussions and comments, which resulted in two aspects that were found most controversial: first, the question of what it means to 'win' the challenge of climate change; and, second, the payoffs of mitigation and adaptation investments. These two aspects were found to also be controversial in the domain literature, as they touch on many scientific unknowns, speculations about future technology and socio-political disputes [7]. Our approach was to offer a range of choices (in addition to the assumptions that we had provided in the first version) to account for more optimistic as well as more pessimistic views represented in the mainstream climate literature.

To address the needs of different winning conditions, we decided to let participants choose between any of the five existing variables in the model that were considered potentially meaningful: income, emissions, baseline damage and residual damage. Further options were whether to play for high or low values and whether winning should be per planet or per region.

The payoffs in our model depend mainly on two functions: the cost of mitigation and the efficiency of adaptation. We therefore decided to let participants change these functions.

Figure 8: One team temporarily gathers around a single tablet to choose the model parameters and winning condition for the next match, while the other team is engaged in discussion.
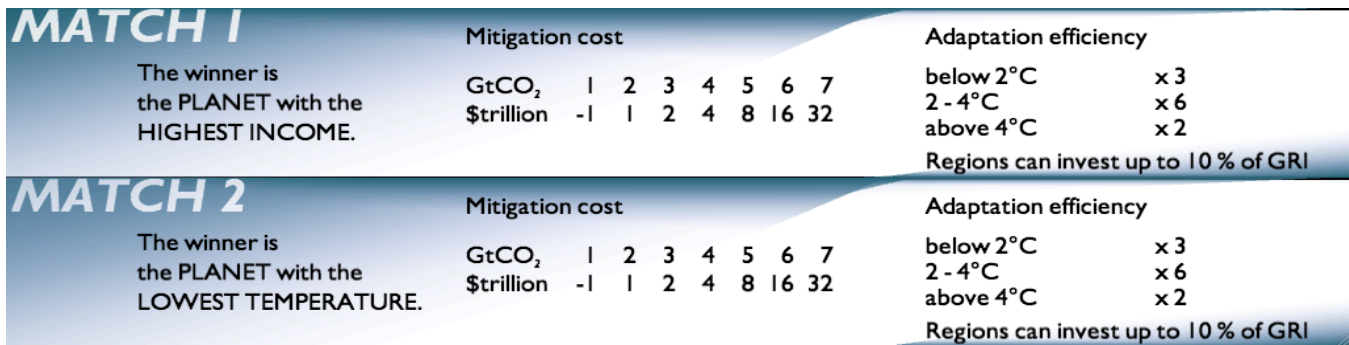
MATCH 1		Mitigation cost								Adaptation efficiency	
The winner is the PLANET with the HIGHEST INCOME.		GtCO$_2$	1	2	3	4	5	6	7	below 2°C	x 3
		$trillion	-1	1	2	4	8	16	32	2 - 4°C	x 6
										above 4°C	x 2
										Regions can invest up to 10 % of GRI	

MATCH 2		Mitigation cost								Adaptation efficiency	
The winner is the PLANET with the LOWEST TEMPERATURE.		GtCO$_2$	1	2	3	4	5	6	7	below 2°C	x 3
		$trillion	-1	1	2	4	8	16	32	2 - 4°C	x 6
										above 4°C	x 2
										Regions can invest up to 10 % of GRI	

Figure 9: Screenshot of the ambient display for the game settings. This view represents what players saw at the end of match 2.

Since the game was structured in short matches, several of which could be played in one session, there was scope for groups to create and test about 4 different variations to the game. We chose to enforce turn-taking between teams for creating variations before each match, such that one team sets the rules for matches 1 and 3 and the other team for matches 2 and 4. The chosen solution involved a series of multiple-choice menus on one single tablet per team (see figure 10).

Since participants could not be expected to memorize all the game settings of all the current and previous matches, a third ambient display was added (figure 9). This enabled a record of their changes to be referenced by the teams. The room layout was changed to a symmetrical arrangement of displays to make space for the third display while ensuring equal conditions for both teams (right half of figure 4).

Choose an Adaptation Scenario

○ High adaptation potential
○ Business as usual
✔ Low adaptation potential

Every trillion invested in adaptation reduces the residual damage by

2 trillion if warming is below   2 °C.
3 trillion if warming is between 2 and 4 °C.
1 trillion if warming is above   4 °C.

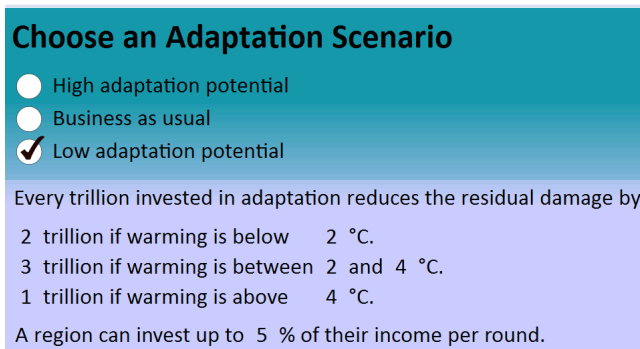A region can invest up to 5 % of their income per round.

Figure 10: The group can choose between 3 different scenarios reflecting different beliefs about adaptation. Similar multiple-choice menus exist for mitigation and the winning condition.

STUDY 2: CONTRIBUTORY SIMULATION

Version 2 of the simulation was deployed in another workshop, similar to the workshop in which version 1 of 4Decades had been deployed. However, the conditions differed in a number of ways. First, participants did not have prior lectures on the topic. Intrigued by the buzz and social atmosphere witnessed in the first workshop using 4Decades, the organizers insisted on scheduling the game as an ice-breaker right at the beginning of the 7-day workshop. To compensate for the lack of prior lectures, the facilitator explained the basic concepts of the topic in a condensed 20-minute micro-lecture prior to introducing the game. To accommodate the lecture and the newly added features, a longer time slot of two hours was scheduled and chairs were provided for all 26 participants. A 15 minute debriefing discussion was also included.

Evaluation

The same data collection methods were used as in study 1, except that the web-based survey was replaced by a paper-based questionnaire for participants to complete in stages after each match, in order to account for their individual, immediate reactions to aspects of the activity. Likert scales and open questions were designed to give insight into usability and learner satisfaction, with an emphasis on the newly added features.

Use of devices and displays

Similar to study 1, the group was immediately engrossed in sharing the tablets and the use of the ambient displays. Talk across the table increased in the later matches. Again, no usability problems were observed or reported regarding the new ambient display or the tablets. Figure 8 shows a team gathered around one single tablet for the purpose of editing the game settings, while the other team were using the break for a discussion. The figure also shows how teams had turned their devices towards the corners of the table, in order to share the devices in a circular layout, with chairs around the table. This orientation was found in both teams. No explicit pairing of participants around the tablets was suggested by the facilitator. Nevertheless, tablets were shared equitably in a seamless way. It appeared that the groups paid more attention to the content on the screens, rather than the physical devices. Small changes to the seating occurred occasionally, as some participants walked around the table for over-the-shoulder interaction with other regions.

Figure 9 shows different winning conditions and mitigation/adaptation scenarios chosen by the participants for the first 2 matches. When deciding about the winning condition for match 3, the team asked the facilitator's permission to create a winning condition that was more complex than the options provided by the multiple-choice

menu. In particular, the team wished to play for 'highest income per planet' with the addition that a team loses immediately if their global temperature rises above 3 degrees. The suggestion was accepted and so the group continued to play with multiple winning conditions.

While teams decided on game settings for the next match, they were often hunched over a single tablet (figure 8), discussing as a whole team. During these discussions participants pondered and clarified concepts, reflecting on earlier settings and strategies and compared the settings with regard to their implications for game strategies. The following excerpt (before match 4) illustrates this:

A: In this [optimistic mitigation] setting we'll break even at the second gigatonne.
B: So that means we can afford a lot more mitigation.
Several: Yeah / That's right / Exactly / Yes we can.
C: Let's go for that one.

Supporting reflection and critical discussion
Similar to study 1, there was much discussion about the relation between inputs and outputs of the simulation. These observations were discussed in the context of specific assumptions that went into the various user-created versions of the simulation. The discussion about winning conditions was concluded with the argument that real-world governments were currently playing a 'one condition game', while they should be playing a 'two condition game'. Several participants suggested that future versions of the simulation should allow the definition of multiple winning conditions as a standard feature.

Several participants indicated that they perceived the session as too rushed and would have preferred fewer matches in exchange for more time to discuss during and between rounds. It was argued that conversations in the team provided important opportunities for peer teaching. Analysis of conversations during game-play showed that much time was spent clarifying domain knowledge which the audience of study 1 had already brought into the game.

Participant satisfaction
Nearly all the participants thought the simulation was very worthwhile. The organizers' wish that the game serve as an icebreaker to help people get to know each other was supported by the ratings. Only 1 out of 26 participants agreed with the questionnaire statement "I would have preferred a 90 minute lecture on the topic instead of the game". 2 somewhat agreed, 2 answered neutral, 9 somewhat disagreed and 12 disagreed. Participants further found that the game provoked a useful discussion about the topic. In the debriefing discussion, it was made explicit that many players would have liked more time for reflection and discussion between the matches. The group almost unanimously agreed that changing the winning condition added an interesting perspective to the game. Further deployments of 4Decades were requested by the organizers.

DISCUSSION
Our findings show how both participatory and contributory simulations can engage large co-located groups in collaborative interactions resulting in much discussion about complex global challenges. In particular, the use of Multiple Linked Representations, presented via ambient displays, can support large group collaboration at multiple levels, enabling teams to have a shared reference of theirs and each other's solutions and ideas. The constrained combination of being able to easily manipulate rules and vary core dimensions of the simulation was found to support a high level of distributed team working. Groups were able to understand the complex system from both a local and global perspective, through having multiple conversations, observations and interactions that took place at and between the tables, tablets and ambient displays.

Adding the functionality of changing the rules in the contributory simulation between rounds also enabled the teams to gain a better understanding of the underlying mathematical model and to see how they connected with the visible dimensions at the user interface. In particular, it enabled them to hypothesize together and contest what-if scenarios of future decades, in terms of climate policies and also in terms of how the planet responds to those policies.

Perhaps, the most striking finding is that collaboration increased over the course of several matches, from operating the tablets in pairs, via sub-team tactics, to team strategies and whole-classroom exchange of information. This development was observed in both sessions and indicates that the ecology of devices supported collaboration at multiple levels.

The provision of very simple constrained interfaces on the tablets meant it was easy for the groups to swap roles from being the drivers of the game, changing the variables for a given planet, to taking a more global role, observing what other members of their and the other teams were doing. Those standing at the tables were also able to relay to each other what the current thinking was and to suggest agreed strategies for subsequent rounds. The fact that no one mentioned problems with the interface or how to use the system suggested that it was for the large part transparent, enabling them to focus on their interactions with each other.

Future iterations of 4Decades could increase the scope of how participants are able to interact with the simulation, for example, entering arbitrary numbers, float numbers, text or visual programming. This would allow the exploration of more sophisticated modeling tasks but the potential downside is that the participants may focus more on the simulation and less on discussing their strategies, trade-offs and solutions, with each other.

In sum, key design features that contributed to the success of using the contributory simulation include:

• the transparent interface and distributed system of displays not requiring prior learning or knowledge.

• the constraints of the tablet interface (only giving local, short-term information and control), so participants needed to collaborate beyond the tablets in order to effect strategies on a global and long-term level.

• the gradual increase of real-time data on the team-shared ambient displays (availability of information).

• no absolute winning condition, but criteria that require teams to compare, interpret and discuss each other's results.

This suggests that this type of interactive simulation could be generalized to other learning settings for complex challenges and global problems, such as pandemics, waste, water and energy.

CONCLUSIONS AND FUTURE WORK

This paper introduced the notion of Contributory Simulations based on the iterative design and in-the-wild evaluation of 4Decades. Our findings show that Contributory Simulations using a distributed ecology of devices and displays can be a powerful way of putting the material learnt in lectures into the hands of the participants, enabling much excited and engaged discussion to ensue. Importantly, using tight constraints on awareness, control and availability of information was seen to engender beneficial aspects of collaboration. In particular, collaboration increased over time from the local to the global. To investigate the generalizability of our observations, we are planning to conduct a series of follow-up studies with Contributory Simulations for a range of audiences, covering a variety of topics. These studies will further explore different designs for allowing large co-located groups to make quantitative and structural changes to computational models.

REFERENCES

1. AlAgha, I., Hatch, A., Ma, L., and Burd, L. Towards a teacher-centric approach for multi-touch surfaces in classrooms. *Proc of ITS Tabletop*, ACM (2010).

2. Colella, V. Participatory simulations: Building collaborative understanding through immersive dynamic modeling. *The Journal of the Learning Sciences* 9, 4 (2000), pp. 471–500.

3. De Jong, T., and Van Joolingen, W. Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research* 68, 2 (1998).

4. DiSessa, A. *On "Learnable" Representations of Knowledge: A Meaning for the Computational Metaphor.* Massachusetts Institute of Technology, A. I. Laboratory, 1977.

5. Fanning, R., and Gaba, D. The role of debriefing in simulation-based learning. *Simulation in Healthcare* 2, 2 (2007), 115.

6. Faria, A., and Wellington, W. A survey of simulation game users, former-users, and never-users. *Simulation & Gaming* 35, 2 (2004), 178.

7. Hulme, M. *Why we disagree about climate change : understanding controversy, inaction and opportunity.* Cambridge University Press, Cambridge, 2009.

8. Jonassen, D., and Strobel, J. Modeling for meaningful learning. *Engaged learning with emerging technologies* (2006), 1–27.

9. Klopfer, E., Roque, R., Huang, W., Wendel, D., and Scheintaub, H. The simulation cycle: Combining games, simulations, engineering and science using StarLogo TNG. *E-Learning and Digital Media, E-Learning and Digital Media*, Vol.6, No. 1, pp. 71–96

10. Kreitmayer, S., Peake, S., Laney, R., and Rogers, Y. Designing a large multi-player simulation game to encourage reflection and critical debate. *Proc. of ECGBL '10* (2011).

11. Lyons, L., Lee, J., Quintana, C., and Soloway, E. Preliminary evaluation of a synchronous co-located educational simulation framework. *Proc. of CHI '06*, ACM (2006).

12. Moher, T. Embedded phenomena: supporting science learning with classroom-sized distributed simulations. *Proc. of CHI '06*, ACM (2006), 691–700.

13. Roschelle, J., Tatar, D., Chaudbury, S., Dimitriadis, Y., Patton, C., and DiGiano, C. Ink, improvisation, and interactive engagement: Learning with tablets. *Computer* 40, 9 (2007), 42–48.

14. Stroup, W., Ares, N., Hurford, A., and Lesh, R. Diversity-by-design: The what, why, and how of generativity in next-generation classroom networks. *Foundations for the future in mathematics education* 367 (2007).

15. Turkle, S. From powerful ideas to powerpoint. Convergence: *The International Journal of Research into New Media Technologies* 9, 2 (2003).

16. Wilensky, U., and Stroup, W. Learning through participatory simulations: network-based design for systems learning in classrooms. *Proc. CSCL '99,* ISLS (1999).

17. Wilensky, U. and Reisman, K. Thinking like a wolf, a sheep, or a firefly: Learning biology through onstructing and testing computational theories - an embodied modeling approach. *Cognition and Instruction*, 2006

18. Yuill, N., and Rogers, Y. Mechanisms for collaboration: A design and evaluation framework for multi-user interfaces. To appear in *TOCHI*, ACM (2012).