Interactive Surfaces and Spaces: A Learning Sciences Agenda

Michael A. Evans, Virginia Tech, 306 War Memorial Hall, Blacksburg VA 24060, mae@vt.edu
Jochen Rick, EduTech, Saarland University, Campus C5 4, Saarbrücken, D-66123, j.rick@mx.uni-saarland.de
Michael Horn, Northwestern University, 2120 Campus Drive, Evanston IL 60208, michael-horn@northwestern.edu
Chia Shen, Harvard University, 33 Oxford St, Cambridge MA 02138, cshen@seas.harvard.edu
Emma Mercier, James McNaughton, Steve Higgins, Elizabeth Burd
Durham University School of Education, Leazes Road, Durham, DH1 1TA, UK
emma.mercier, j.a.macnaughton, s.e.higgins, liz.burd @durham.ac.uk
Mike Tissenbaum, Michelle Lui, and James D. Slotta, University of Toronto, 252 Bloor St. W., Toronto, Canada
miketissenbaum@gmail.com, michelle.lui@utonronto.ca, jslotta@gmail.com
Roberto Martinez Maldonado and Andrew Clayphan, University of Sydney, roberto@it.usyd.edu.au,
andrew.clayphan@sydney.edu.au

Abstract: Interactive surfaces and spaces are entering classrooms and other learning settings. This symposium brings together leaders in the field to establish a coherent research agenda for interactive surfaces inside the learning sciences. We demonstrate the broad applicability of these technologies, outline advantages and disadvantages, present relevant analytical frameworks, and suggest themes to guide future research and application.

Supporting Learning with Interactive Surfaces and Spaces

Though the mouse-and-keyboard controlled interface is still the standard in classrooms, museums, and homes, interactive surfaces and spaces are emerging as a prominent alternative in the form of handhelds, tablets, tabletops, and whiteboards, used alone or in provocative configurations. As these devices become more capable and affordable, the case for applying these technologies to support learning becomes increasingly compelling. Now is the time for the learning sciences to get involved—to research the benefits and deficits of these technologies and to develop learning solutions that take advantage of the former while avoiding or compensating for the latter. The goal of this interactive poster session is to exhibit current work in this field.

Gesture, Metapragmatics & Multimodal Analysis Techniques for Surfaces & Spaces
Michael A. Evans

Our work examines PreK students (ages 4-5), a group of three boys compared to a pair of girls attempting to solve geometric puzzles on a tabletop (Evans, Feenstra, Ryon, & McNeill, 2011). Results showed significant differences in the way that boys and girls negotiated the task at hand. These differences can be located in the relative frequency of object co-references and task co-references, and also in the function of metapragmatic speech, either to assert one's presence and correctness or to co-create a coherent structure for the interaction. Accordingly, the boys and girls also differed in the way that they involved the teacher in their interactions. Where our work extends the current literature is by investigating multimodal interaction among peers and triads around a multi-touch tabletop surface. For the reported research we focus on the SMART Table™, a tabletop computer that projects bottom-up images on a horizontal surface that can be directly manipulated by users simultaneously. The incorporation of the SMART Table in our research allows us to experimentally manipulate learning conditions with changes to the software, requiring less reliance on verbal cues and policy. Thus, our research examined the interrelationships among social constraints (free, divided, and single ownership modes) and instructional technologies (physical and virtual manipualtives) using a multi-touch surface. The questions that follow from this arrangement of social constraints and instructional technologies are these: 1) How does discourse (quality and type) differ among the three levels of social constraint? 2) How does discourse (quality and type) differ between physical and virtual manipulatives? 3) Are there distinct patterns of interaction between social constraint and instructional technologies (i.e., physical and virtual manipulatives? Multi-modal techniques that examine talk, gesture, gaze, and activity are not unknown to the LS research community. Works by Strijbos and Stahl (2007) have demonstrated the benefits of using multimodal techniques to examine collaborative learning. Though Cakir et al. (2010) were investigating the use of a digital whiteboard in a virtual mathematics chat room setting, results from this work corroborate our emphasis on focusing on coreferential or joint problem solving moments in the discourse to find traces or evidence of group cognition. Moreover, the techniques adopted by Cakir et al. (2010) justify our adoption of microgenetic ethnographic methods to identify discrete moments of group cognition. Where our work is distinguished from theirs is the emphasis of co-located interaction and collaboration. The virtual chat room space decreases, or entirely removes, indications rendered by gesture. Though our work aligns in emphasizing gaze and how it might establish a dual space, we extend these efforts by including the gestural component that has been found critical in conveying mathematical ideas. Collaboration emerges when participants explicitly describe themselves as collaborating, or implicitly fit themselves into the structures we associate with collaboration as a way of interacting, such as turn-taking

structures marked by both time and repeating poetic structures from turn to turn. Within the scheme of references and co-references, metapragmatic speech that functions to make an interaction coherently collaborative is necessarily co-referential (McNeill et. al., 2010). Collaboration operates on a scale larger than a moment; an emergent collaborative character of 'what we are talking doing now' depends on chain linkages of collaborative metapragmatics throughout an interaction.

Proportion: A Tablet Application for Supporting Collaborative Learning
Jochen Rick

I designed the Proportion iPad application to research the potential of one table to support collaborative learning. For this application, the tablet is positioned vertically on a table in front of two learners, aged 9–10. Learners work together to solve a series of ratio / proportion problems. The interface has two columns—one on the left and one on the right. For each problem, the children must size the left and right columns in proportion to their respective numerical labels. Through using Proportion, they gain competence in proportional reasoning.
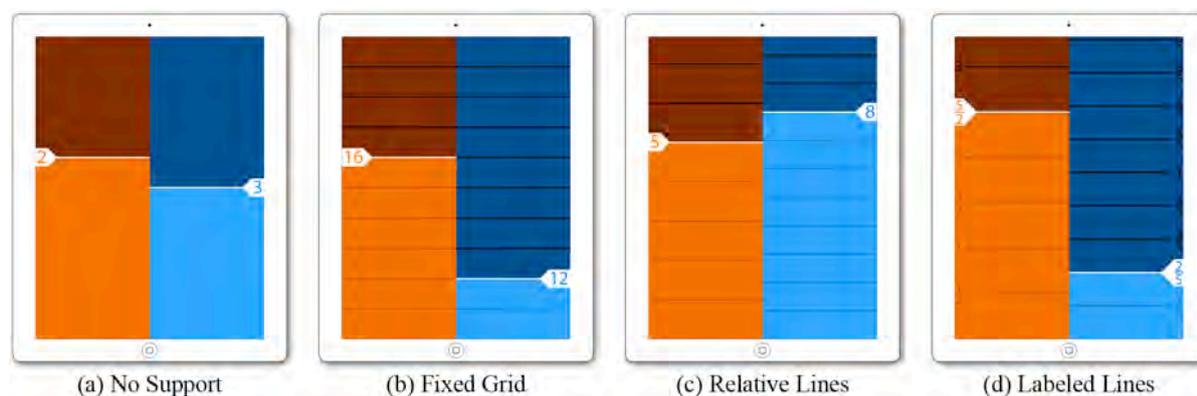
Figure 1. Four interfaces to scaffold learners in solving problems.

Proportional reasoning is a challenging mathematical domain. One problem is that it is usually taught and tested with mathematical notation through word problems; these provide neither *feedback on task progress* nor *tools to scaffold users*. Proportion provides several interfaces to scaffold users (Figure 1). Without any support (a), learners must estimate the ratios. Embodied proportional reasoning, relying on rules-of-thumb (e.g., larger denominator means smaller amount) and estimation (e.g., 9 is about twice as much as 4), are particularly important for learners to relate their everyday experiences to mathematical concepts (Abrahamson & Trimic, 2011). Proportion provides two levels of *feedback on task progress*. If the ratio of the two columns is close to the correct answer, a small star with a "close" label is shown. If the ratio is within a very small zone, then it is pronounced as correct, a large star with a "correct" label is shown, and the application moves on to the next problem. With a fixed 10-position grid (b), learners have precise places that they can target, thereby using their mathematical understanding of the task to quickly solve problems. One strategy is for users to select the grid line that corresponds to their respective numbers. This works well for simple ratios (e.g., *4 : 9*). For the common-factor problem shown in Figure 1b, that strategy does not work. As illustrated, the children tried a novel strategy of positioning the columns based on the last digit of the number. Of course, this did not work and they were able to realize that this was not a viable strategy. With relative lines (c) that expand based on the position of the columns, learners can use counting to help them solve the problem. They can also learn more embodied strategies, such as maximizing the size of the larger column to make it easier to correctly position the smaller column. When the lines are labeled (d), other strategies can be supported. For instance, in the fraction-based problem shown, a useful strategy is to arrange columns so that whole numbers (e.g., *1*) are at the same level.

Proportion has been through two rounds of user testing to improve the interface and fine-tune the sequence of problems. The research with Proportion aims to shed light on two broad research topics. First, it will investigate how children communicate to collaborate. Previous work on interactive tabletops has demonstrated that children readily use their interactions with the interactive surface to communicate with their partners (Rick, Marshall, & Yuill, 2011). This work aims to tease apart the role of verbal and gestural communication. Second, it will investigate issues of equity of collaboration for tablet-based collaboration. On tabletops, it becomes difficult for users to access all parts of the surface; therefore, users tend to concentrate their interactions in areas closer to their position at the tabletop (Rick et al., 2009). Such separation is not possible for a tablet: Every user has good access to all parts of the interactive surface. Proportion was designed to have an interface split across the users. Children quickly grasp that they should control the column on their side. Do children stay with this convention? What happens when the convention breaks down? How does this affect the equity and effectiveness of the collaboration?

Multi-Touch Tabletops in Natural History Museums

Michael S. Horn and Chia Shen

In this presentation, we discuss one exhibit that we have designed for this project called Build-a-Tree (or BAT for short). Build-a-Tree is a multi-level puzzle game that asks visitors to construct trees showing the evolutionary relationships of organisms (Figure 1). We represent organisms using black silhouettes superimposed on colored circles that visitors drag around the table. Touching any two circles together joins them into a tree. The reverse action, dragging circles apart, removes an organism from an existing tree. We designed the game levels to be increasingly difficult and to build on one another conceptually. For example, level four asks visitors to construct a tree showing the relationships of spiders, scorpions, and insects. These same relationships appear again as sub-problems in larger puzzles on levels six and seven. We conducted a study of Build-a-Tree at a well-known university natural history museum. In the study, we recruited and video recorded 30 family groups (consisting of at least on parent and one child) using the exhibit. We transcribed visitor conversation up to and including the first six levels of game play.
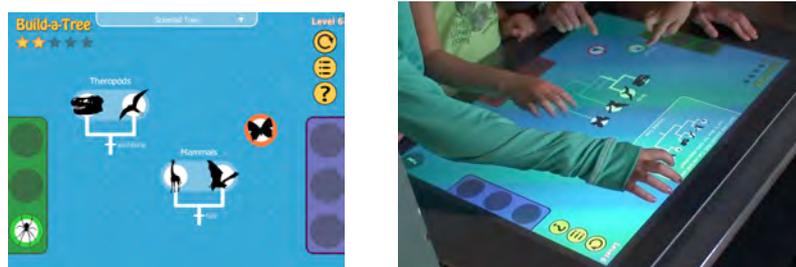
Figure 1. Screenshot of the Build-a-Tree game (left) and visitors playing the game in the museum (right).

Based on these data, we iteratively developed a coding scheme that included three high-level categories: *game talk*, *content talk*, and *off-topic talk*. Among our findings, we saw that visitors spent long periods of time interacting with the exhibit (14 minutes on average; SD = 6) and engaged in minimal off-topic conversation (off-topic utterances occurred 0.16 times per minute on average; SD = 0.3). However, while engagement was high, evidence of visitor reasoning about evolutionary relationships was less satisfactory. Content related talk made up 26.6% of the overall conversation, but statements about relationships were rarely backed up with explanation. We see this study as one point in an ongoing design-based research effort, and we are in the midst of updating our design based on this analysis to increase evolutionary reasoning in visitor conversation. In attempting to explain these results, it was clear that game talk played a significant role in helping visitors coordinate their activity around the tabletop. For example, negotiating turn-taking was a common mechanism for groups consisting of multiple children. This is perhaps not surprising. In ethnographic research of children playing video games in homes, Stevens, Satwicz, and McCarthy (2007) observed a variety of learning arrangements that young people spontaneously adopted to support game play. In effect, when visitors encountered our game in the museum, they already had a repertoire of social practices on hand to support collaborative interaction. Identifying similar ways to cue effective social practices will be critical to support the use of tabletop surfaces in informal learning environments.

Orchestrating Learning in the Multi-touch Classroom: Developing Appropriate Tools

Emma Mercier, James McNaughton, Steve Higgins, Elizabeth Burd

Interactive surfaces provide new ways to support collaborative learning with technology, however, new technology in classrooms has rarely lived up to its promise, in part because less attention has been paid to the pedagogical and classroom orchestration issues of introducing new technology (Dillenbourg & Jermann, 2010; Slotta, 2010). The SynergyNet multi-touch classroom (Higgins, et al., 2011) was designed with four networked, multi-touch student tables, teacher tools and an interactive whiteboard (IWB) that allow for the movement of content between the tables and to the IWB, and teachers tools to manage table functions, deliver content and monitor activities. Over two years we have

Fig 1: Multi-touch Classroom

developed tools for the teacher to use, iteratively designing the teacher controls as we learn more about the orchestration needs of a multi-touch classroom.
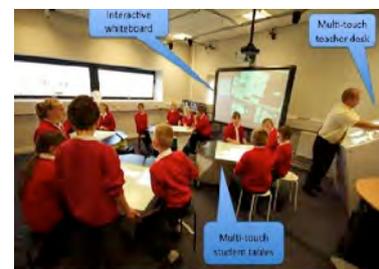
Stage 1: The Multi-touch Classroom and Orchestration Desk

Initially teacher orchestration tools were on an angled multi-touch table (Fig. 1). These controls were used to select activities for the class, send content to and monitor the student tables, and project content to the IWB.

This classroom was used to study a series of collaborative learning activities; two researchers with prior teaching experience taught the classes. For each of the activities, the teacher started the activity by sending the content to the student tables, then walked around the room, intervening to support groups where necessary, and locking the tables for whole-class discussions. For this the teacher projected content from one of the student tables to the IWB; the group whose table was displayed described their process and ideas. The teachers noted that not having access to controls as they moved around the room constrained their ability to take an interesting idea from one group to the whole class to support uptake of student ideas.

Fig 2: Mobile Orchestration

Stage 2: Mobile Orchestration Devices

To allow control while the teacher moved around the room, the teacher controls were transferred from the orchestration desk to an iPad (Fig. 2), which the teacher carried and used to make changes to the activities and view information about students' contributions to tasks. The control features allow the teacher to start, pause or end an activity, project the content of a student table to the IWB, and move content from one table to the next. In addition, the teacher can view the work that the students are doing to all quick intervention if a student appears to be struggling. In one study, a member of the research team taught three classes using the iPad, reporting that the ability to control the activities from anywhere in the room was useful, but that having to hold and interact with the tablet took away from some of the ability to support the students by working directly on the student tables.

Stage 3: Gesture-based Teacher Controls

Currently, we are moving away from using direct-touch devices for orchestration, building on tracking capabilities of depth cameras such as the Microsoft Kinect. The teacher is identified by the Kinect, which is mounted on the teacher orchestration desk. Using a series of pre-defined gestures the teacher can manage the student tables from anywhere in the classroom (Fig 3), including locking and unlocking the students' tables, taking screen-shots of a particular table and projecting the content from one table onto the IWB. These should provide the teacher with enough control to manage the technology, while future development will explore the use of teacher-specific tools that the

Fig 3: Projecting from Tables to IWB

teacher can activate on any of the interactive surfaces in the room, building on the recognition capabilities of the Kinect, which would allow the teacher to conduct more complex functions without the need for an additional device.

Issues of orchestrating collaborative learning in a technology enhanced classroom are concerned with both the management of the technology and ways in which technology can provide additional information for optimal teacher intervention when groups get stuck or go astray. While our orchestration tools have been designed to support both needs, some of the management issues and technical interaction and control challenges must be solved before a teacher can give all their attention to the learning activities of their students.

Gesture, Scaffolding Collaborative Knowledge Construction in High School Physics with Tablet Computers and interactive White Boards

Mike Tissenbaum and James D. Slotta

To effectively integrate collaborative technologies and practices into Science, Technology, Engineering, and Math (STEM) curriculum many learning theorists have advocated a knowledge community approach, where students work together to investigate salient issues, collaboratively develop theories, build ideas, and develop conclusions with technology as a central scaffold to the learning process (Brown & Campione,1996).

Handheld tablets are increasingly popular within these technology mediated environments, as they allow for a 1:1 device to student ratio which can improve the organization and distribution of materials, and the coordination, communication, and negotiation of students within real-time activities (Zurita & Nussbaum, 2004). However, handheld screen sizes can inhibit group collaboration, and as such, should be augmented with large-format displays in order to better facilitate small group and whole class interactions (Tissenbaum, Lui, Slotta in press). By using large, interactive surfaces, we can more easily mimic the ecological dexterity of paper, allowing students to rearrange, reassemble, and annotate aggregated products of prior interactions (Everitt et al., 2005). The use of such technologies can allow students to collaboratively interact within an information space, build shared representations, and allow students to "slide" information between their own device and these representations.

Another aspect of this combination of technologies (i.e., within a single physical setting) is the ability to dynamically adjust the representations and scripts sent to devices within the room. This capacity to

"orchestrate" the pedagogical flow of students, materials and activities can facilitate specific instructional designs, and serve to embody the broader epistemological goals of the research (Tissenbaum, Lui, Slotta, in press). The "room" could conceivably respond to individual students, moving them between groups or activities, or sending relevant materials. To achieve these complex pedagogical moves we require a robust technology infrastructure, including a role for intelligent software "agents" that can perform data mining and help coordinate pedagogical flow (Slotta, 2010). To this end, our group has been developing a flexible, open source "smart classroom" framework called SAIL Smart Space (S3) that supports the integration of technologies, including the aggregation, interpretation and response to student activities. The goal is to develop a technology environment capable to supporting a wide range of collaborative inquiry and knowledge construction scripts including interactive media and multi-touch surfaces. Our current design involves two grade 12 high school physics classes each involved in a two-day smart classroom activity, where students developed their understandings of real-world physics phenomena, in part through classifying physics problems, mapping those problems to the phenomena, and "setting up" problems concerning the phenomena, in ways similar to physics experts (Chi, Feltovich & Glaser, 1981).
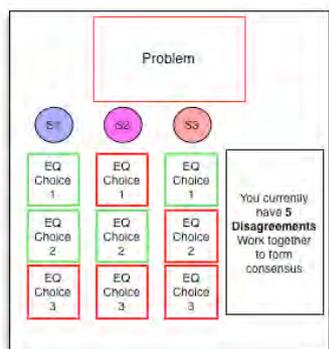
Figure 1: In-Class collaborative equation negotiation
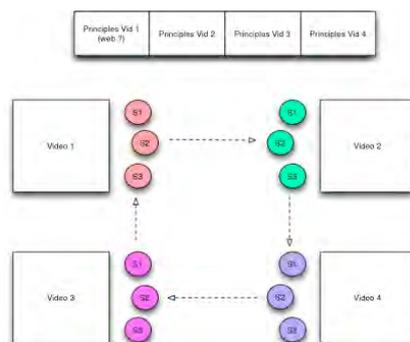
Figure 2: Smart Classroom configuration (Step 1)
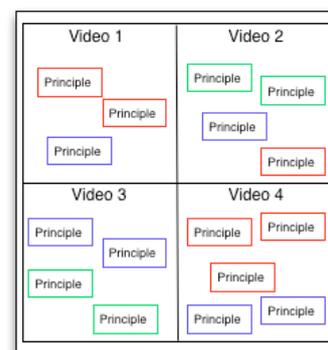
Figure 3: SMART Board aggregated principle screen

Students first worked at home to sort various physics problems according to a core set of underlying principles (Newton's laws, conservation of energy, and equations of motion), before working in small groups in a unique form of "equation sorting and negotiation" towards solving assigned problems. Throughout the activity intelligent agents performed student grouping based on past work, and tracked in-class activity, providing student groups feedback about their progress on consensus on their final equation sorts (Figure 1). The teacher used his own touchscreen tablet to "flip" through the aggregated group pages (like pages in a book), gaining insight into groups' progress. During the smartroom activity students entered the room (Figure 2) in batches of 12, and divided into 4 groups of 3. Each student was given a set of sub-principles from one of three larger themes, and moved from station to station (by a "traffic flow" agent) and: (1) watched a video clip of a popular Hollywood movie that illustrated or violated one or more physics principles, and (2) "flung" (swiped from tablet to wall) any of their assigned principles at the video wall, before moving on to the next station as directed by the agent. As students moved throughout the room, flinging principles, the aggregated collections appeared on the SMART boards at the front (Figure 3). Once completed, agents regrouped students to one of the four stations based on their tags from the previous step and provided a "scaffolding question" to help them approach the video as a real physicist would. Using their tablets students submitted "assumptions" about the scenario within the video (e.g., the weight or speed of a car, if relevant to "solving" the implicit problem) and collectively debated these assumptions, towards forming consensus. In the next "pedagogical step", students moved to a new station, where they saw the assumption of the previous group and received a small set of problems, assigned by an agent based on the principles attached to the video (from the homework stage). Their task was to pick the problem that most directly helped in understanding the video, and its related equations (attached during the pre-activities). The groups were reconfigured for a final step, where they used the work of previous groups to order the sequence of equations towards solving the implicit physics problem by dragging equations to a field on their tablets and negotiating any conflicts (similar to the Day 1 activity). The activity concluded with the teacher engaging the class in a debrief around the final results and using the SMART boards to show the evolution of the class' constructed knowledge.

This intervention highlights how a smart classroom setting coupled with tangibly interactive technologies can achieve a variety of class configurations, interactions with student generated content, and epistemological goals that could not be achieved by traditional paper and pen approaches and physical layouts. Our demo will create a simplified activity that can be performed by session participants within the context of

this symposium (i.e., in 15 minutes) and also provide a video of our actual smart room session and accompanying poster.

EvoRoom: An Immersive Simulation for Smart Classrooms
Michelle Lui and James D. Slotta

EvoRoom is a room-sized simulation of a rainforest environment designed for a "smart classroom" in an urban high school. Collaborating closely with a biology teacher, we designed immersive learning activities for teaching topics on biodiversity and evolution. These immersive simulation activities engages students in collective inquiry, where students take on the role of "field researchers" and use aggregated student inputs and collective knowledge to solve a problem or to understand a phenomena. Students work in various group configurations (e.g., individually, small groups, and as a collective) to complete tasks delivered to them on their personal tablet computers. The tablets, which contain custom designed application, provide scaffolds, place students in small groups, and give real-time updates and dynamic resources. Student contributions (e.g. written reflections) are aggregated and displayed on interactive whiteboards (IWBs) as they come in, and stored within a collective knowledge base. There are a number of surfaces involved in an immersive simulation, and each affords a different interaction (e.g., student-to-student interactions, student-to-teacher, and student-to-digital-artifacts). This poster examines how students engaged with the various components of EvoRoom. Below, we describe the environment, outline one of the immersive activities and detail the outcomes with respect to the various surfaces involved in the sessions, relating student engagement to the kinds of interactions that these components encourage. Our technology framework, Sail Smart Space (S3) supported the activity by providing a portal that where students login to the experience, an intelligent agent architecture that tracked real-time communications, and a central database that housed curriculum materials and the products of student interactions (Slotta, 2010). The room is set up with two sets of large projected displays (6 meters wide, achieved by "stitching" together 3 projector displays) that students would examine together (Figures 1, 2). The simulation files are networked and controlled with a custom tablet application, allowing the teacher to manage the time spent in each portion of the activity, controlling the pedagogical flow within the room. Two IWBs are located at the front of the room to display aggregated student inputs, which both teacher and students manipulate as a locus of discussions.

In this study, 45 students from two sections of our co-design teacher's grade 11 Biology course spent 75 minutes (i.e., one class period) working on the activity. Students were video recorded and student artifacts (e.g. written notes) were collected for analysis. A post activity questionnaire that queried student perceptions of environment was answered by 39 of 45 students.
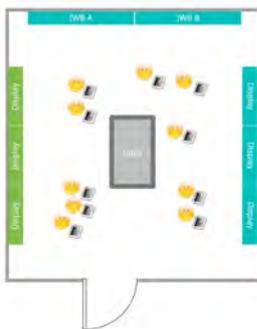
Figure 1. Smart classroom setup   Figure 2. Three projectors make up a sidewall of EvoRoom

Students who visited EvoRoom were each given a tablet to work with; on the walls were different versions of the rainforest ecosystem, each showing an outcome from a specific environmental variable (e.g., high rainfall, tsunami…etc.). We designed a tablet-based interface that challenged students to explore the differences between these rainforests and to match them to the different environmental variables. As part of the activity, a "sorting agent" assigned students different organisms to look for. When students scanned QR codes at the different stations, the agents recognized their location and sent further, contextualized instruction to the tablets. For each station, students were prompted to record whether their assigned organisms were present. All responses were aggregated on the IWB at the front of the room, presenting a tally for reference by teachers and students alike. Students worked in groups of two or three to begin eliminating rainforest stations that likely did not result from their assigned variable. During group activities, different tasks were distributed to different students in each group. For example, in a group of three, one person was designated to be the scribe, while the second group member was instructed to look up information from field guide, with the third assigned to look up prediction from their class website (accessed as a link on the tablet). All of the group's decisions and notes were

collected on the IWB at the front of the room. The aggregated results were all shown on the IWB, which the teacher used to lead a discussion of how the variables affect the flora and fauna of the rainforest ecosystem.

Our analysis of student performance and perceptions in EvoRoom uncovered several findings about student learning in immersive environments. Results of the classroom trial indicate that students are able to effectively allocate their attention between the immersive simulation and the various technologies supporting their tasks (e.g., tablets, laptops). Of the 16 groups that participated in the activity, 8 groups (50%) correctly identified the related rainforest as their first choice, while 4 (25%) groups chose the correct rainforest as their second choice. Video analysis will allow researchers to better understand which patterns of interactions were more conducive to supporting collective inquiry. On a scale of 1 to 10 (with 1 being unsuccessful and 10 being very successful), students rated the use of personal tablets in the smart classroom with an average of 7 ($SD =$ 2.76). The immersivity of EvoRoom was rated highly, at an average of 9 out of 10 ($SD = 1.48$). One student indicated that the QR scanning feature offered a more "hands-on" experience compared to, for example, selecting an option from a list of item. On the whole, we found that students were excited about the immersivity of EvoRoom and the use of tablet computers for supporting their learning.

Analysing and Supporting Collaborative Learning at the Interactive Tabletop
Roberto Martinez Maldonado and Andrew Clayphan

One of the major challenges faced when developing computer-supported collaborative learning tools is the provision of adequate support to the activities according to the particular needs of the group members. In group work, teachers often divide their attention among groups and they typically focus on the groups which they think need more advice and guidance. As a result, they typically only see the final product. The process to build such a solution and individual contributions may be hard to determine. Emerging pervasive shared devices, such as multi-touch interactive tabletops, are very promising, providing an enriched learning environment and a medium to capture groups' social dynamics to adapt the affordances of the tool to students and their teachers' needs. We present Collaid (Martinez *et al.*, 2011), a digital framework to support collaboration at the classroom by providing both support to learners and awareness tools for their teachers in a multi-tabletop classroom. Collaid augments the capabilities of the hardware with a set of key features: identification of proximity of learners around a tabletop and authorship of each touch (using a depth sensor situated on top of the surface device), recognition of people speaking and capture of multimodal data about collaboration (video, audio and application logs in a common repository). Any touch or oral participation around the tabletop is automatically traced, with its author, and logged.

Figure 1. Examples of Collaid in use.

We show how personal devices can be used to establish a link so to identify the source, provide personalisation and tracking of learners during activities and across activities. We demonstrate how our system uses technology for ways to capture the digital footprints of users without impacting the main task. This provides the opportunity to model groups' participation and mirror back indicators of collaboration to their teachers so they can best orchestrate the collocated collaborative process. Collaid is presentedin two learning domains: collaborative concept mapping and brainstorming. Concept mapping is a technique that permits learners to visually externalise a representation of their knowledge about a topic. It permits group members to confront different perspectives to solve misunderstandings and build new knowledge. The interface permits learners to merge their individual concept maps in face-to-face sessions at the tabletop. Secondly, we demonstrate brainstorming (Clayphan *et al.*, 2011) on an interactive digital tabletop as a collaborative activity to help groups generate original ideas encouraging egalitarian and cooperative participation. Digital tabletops combine natural face-to-face discussion found in conventional settings with increased flexibility gained from computerised support. Tabletops allow collaborative process to be captured, helping measure learner

engagement. We present work on tabletops and brainstorming with scripted collaboration around user control. We identify stages in the process and enable mechanisms to guide learners with the aim of improving support. We demonstrate the system with a recent integration of user tracking, allowing deeper metric collection and understanding of active contribution.

Conclusion

As demonstrated in this symposium, interactive surfaces and spaces offer a new computing paradigm to supplement, complement, or even supplant the desktop user interface. Learning scientists and educational technologists adopting these technologies have begun to carve niches for themselves in education. Over time, more powerful hardware will become available at a more affordable price, software development environments will improve, more applications will be available, and our understanding of how to use them to support learning will increase. Consequently, these interactive environments will play an increasing role in research and in the general support of learning.

References

Abrahamson, D., & Trimic, D. (2011). Toward an embodied-interaction design framework for mathematical concepts. In *Proceedings of IDC '11* (pp. 1–10). New York: ACM Press.

Brown, A. & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments. 289-325.

Cakir, M.P., Zemel, A., & Stahl, G. (2010). The joint organization of interaction within a multimodal CSCL medium. *International Journal of Computer-Supported Collaborative Learning,4*(2), 115-149.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*(2), 121-152.

Clayphan, A., Collins, A., Ackad, C., Kummerfeld, B. and Kay, J. Firestorm: A brainstorming application for collaborative group work at tabletops, Proc. of Interactive Tabletops and Surfaces ITS'11, ACM (2011), pages 162-171.

Dillenbourg, P., & Evans, M. (2011). Interactive tabletops in education. *International Journal of Computer-Supported Collaborative Learning*, 6(4), to appear.

Evans, M.A., Feenstra, E., Ryon, E., & McNeill, D. (2011). A multimodal approach to coding discourse: Collaboration, distributed cognition, and geometric reasoning. *International Journal of Computer Supported Collaborative Learning, 6*(2), 253-278.

Higgins, S. E., Mercier, E. M., Burd, E., & Hatch, A. (2011). Multi-touch tables and the relationship with collaborative classroom pedagogies: a synthetic review. *International Journal of Computer-Supported Collaborative Learning*, 6(4), 515–538.

Martínez R., Collins A., Kay J., Yacef K., Who did what? Who said that?: Collaid: an environment for capturing traces of collaborative learning at the tabletop, *Proc. of Interactive Tabletops and Surfaces ITS'11, ACM* (2011), pp. 172-181.

McNeill, D., Duncan, S., Franklin, A., Goss, J., Kimbara, I., Parrill, F., Welji, H., Chen, L., Harper, M., Quek, F., Rose, T. & Tuttle, R. (2010). "Mind-Merging". In a Festschrift for Robert Krauss, Ezequiel Morsella (ed.), *Expressing oneself / expressing one's self: Communication, language, cognition, and identity*. London: Taylor and Francis.

Rick, J., Harris, A., Marshall, P., Fleck, R., Yuill, N., & Rogers, Y. (2009). Children designing together on a multi-touch tabletop: An analysis of spatial orientation and user interactions. In *Proceedings of IDC '09* (pp. 106–114). New York: ACM Press.

Rick, J., Marshall, P., & Yuill, N. (2011). Beyond one-size-fits-all: How interactive tabletops support collaborative learning. In *Proceedings of IDC '11* (pp. 109–117). New York: ACM Press.

Slotta, J. D. (2010). Evolving the classrooms of the future: The interplay of pedagogy, technology and community. In K.M\{a}kitalo-Siegl, F. Kaplan, J. Zottmann & F. Fischer (Eds.), *The classroom of the future orchestrating collaborative learning spaces* (pp. 215-242). Rotterdam: SensePublisher.

Stevens, R., Satwicz, T., & McCarthy, L. (2007). In-game, in-room, and in-world: Reconnecting video game play to the rest of kids' lives. In K. Salen (Ed.), *The Ecology of Games: Connecting Youth, Games, and Learning*, pp. 41–66. MIT Press

Strijbos, J. W., & Stahl, G. (2007). Methodological issues in developing a multi-dimensional coding procedure for small group chat communication. *Learning & Instruction. Special issue on measurement challenges in collaborative learning research, 17*(4), 394-404.

Tissenbaum, M., Slotta, J. D., & Lui, M. Co-designing collaborative smart classroom curriculum for secondary school science. *Jorunal of Universal Computer Science*.

Zurita, G., & Nussbaum, M. (2004). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers \& Education, 42*(3), 289-314.