Learning and participation in a persistent whole-classroom seismology simulation

Tom Moher, University of Illinois at Chicago, Chicago, IL 60607 USA, moher@uic.edu

Abstract: This paper presents the results of a six-week unit on seismology conducted in a fifth-grade classroom. The unique feature of the unit involved the use of classroom technology designed to support students' participation in an authentic seismological practice: the interpretation of seismograms to determine the epicenter and magnitude of earthquakes. The goals of the empirical study were (1) to gain insight into the impact of the intervention with respect to student mastery of seismological practice skills, development of conceptual understanding of earthquake distributions, and changes in self-conception as investigative agents, and (2) to investigate student participation in an emerging community of practice over an extended time course.

Introduction

Collaborative learning activities involving multiple heterogeneous roles almost necessarily result in an uneven distribution of learning and participation among individuals, particularly when those activities allow learners some "freedom of choice" in the level of participation and the adoption of working roles. While such designs have the advantage of appealing to individual interests, they run the risk of failing to ensure that students participate in such a way that experience advances learning. This danger is especially cogent when the duration of the learning unit is too short to allow time for students to adopt multiple distinct roles within the broader activity structure.

The use of personal computational technologies affords opportunities for monitoring individual participation, and the instrumentation of learning applications has provided insight into participation, particularly within networked learning communities (e.g., Barab, et al., 2002). However, with the emergence of "ambient" technologies as a complement to personal computational devices, assigning interaction to individuals becomes more challenging. Moreover, in many learning designs, activity is distributed between technology-based interaction and non-technology-based work; since the computer is no longer the sole locus of action, instrumentation of that channel alone fails to provide an adequate picture of participation.

In this paper, we present a study of learning and participation in an episodic fifth-grade classroom activity, *RoomQuake*, in which all of the computational and display devices were "community affordances" shared among the entire class offering a mixture of activity distributed among technological and non-technological artifacts. We developed instruments design to assess learning along two dimensions: skill in authentic seismological practice and conceptual understandings related to the temporal, spatial, and intensity distributions of earthquakes. Using video data collected from an array of ceiling-mounted cameras, we were also able to obtain a relatively complete account of individual student participation among roles and across time. Our goal was to find out how learning and participation were distributed among learners, and how participation evolved over time.

Background

RoomQuake is an exemplar of a broader technology paradigm that uses the physical space of the classroom as the locus of imaginary, persistent Embedded Phenomena (Moher, 2006) that unfold over an extended period of time, and that are investigated (collectively, rather than individually) by using fixed-position computers as "probes" into those phenomena. The design space of the embedded phenomena framework is characterized by four common elements:

- Simulated dynamic scientific phenomena are "mapped onto," and asserted to occur within, the physical space of the classroom.
- The phenomena are represented through distributed media (conventional classroom computers) located around the classroom representing "portals" into that phenomenon, depicting local state information and control affordances corresponding to the mapping between the room and the phenomenon. (Embedded phenomena are "delivered" using a "Phenomenon Server," a web portal that supports configuration and scheduling of the simulation for delivery to any Internet-connected computer running a conventional web browser with a Flash plug-in.)
- The simulations are persistent, running and being presented continuously over extended time periods, concurrently but asynchronously with respect to the regular instructional flow.
- As individuals, in small groups, and as whole classes, students monitor and manipulate the state of the simulation through those media, gathering evidence to solve a problem or answer a question.

The pedagogical basis for embedded phenomena derives broadly from theories of situated learning (Brown, et al., 1989; Rogoff, 1990). The embedded phenomena framework situates communities of practice (Wenger, 1998) (in our case, intact self-contained classes) within authentic activity structures (scientific investigations) for the purpose of socially constructing knowledge of both science concepts and the processes of science as a technical and human endeavor (Duschl, 2000). The extended duration characteristic of embedded phenomena learning units seeks to afford time for movement from the periphery of practice to more central roles (Lave & Wenger, 1991) within an apprenticeship context of emerging expertise among peers and teachers (Bandura, 1977; Brown, et al., 1989). The strategy of situating learners not only within communities, but also within the physical and temporal bounds of the phenomena themselves, further extends the situated learning framework by reinforcing the inseparability of learner from environment and body from mind (Barab & Plucker, 2002).

The activity goal in embedded phenomena learning units is authentic, disciplinary science inquiry (Chinn & Malhotra, 2002). While "inquiry" continues to defy canonical definition, we co-design (with practitioners) learning activities that extend beyond the rote methods and products of scientific investigations, and that invoke problematizations in the processes of science, such as the use of evidence in explanation (Sandoval, 2001), argumentation (Duschl & Osborne, 2002), and treatment of anomalous data (Chinn & Brewer, 1983).

A wealth of prior empirical work involving in-depth investigations of technology-supported inquiry learning in science with authentic evidence collection and reasoning tasks has shown that engaging in authentic science practice activities facilitate understanding in science as well as motivation and interest (e.g., CTG, 1993; Edelson, 1998; Krajcik, et. al, 1998; Smith & Reiser, 2005). The proposed instructional interventions—characteristic of a pedagogical strategy involving the use of "immersion units" (Schunn, et al., 2004), group inquiry projects (such as the Northwestern/Michigan LETUS project, the Georgia Tech LBD projects, Wisconsin's MUSE project, etc.) that focus on rich investigations of complex phenomena or design challenges extending over multi-week periods with an emphasis on model elaboration and argument construction—builds on existing research by investigating novel methods of embedding inquiry activities within classroom space and time.

By engaging students in authentic science practices, we hope to particularly increase the intrinsic motivation of students to learn science. Research in educational contexts suggests that students are highly motivated by engaging in authentic scientific practice, and that opportunities for both autonomy and challenge are the critical aspects of a learning environment that determine whether it will be highly engaging for students (Dede, et al., 2005). The present activities are designed with this literature in mind, to require both activity and autonomy on the part of each learner, as well as a significant and non-trivial authentic problem to be solved. Further we hope to increase students' sense of self-efficacy, agency and empowerment to see themselves as legitimate scientific investigators (e.g., Bandura, 1997, Pintrich, 2003).

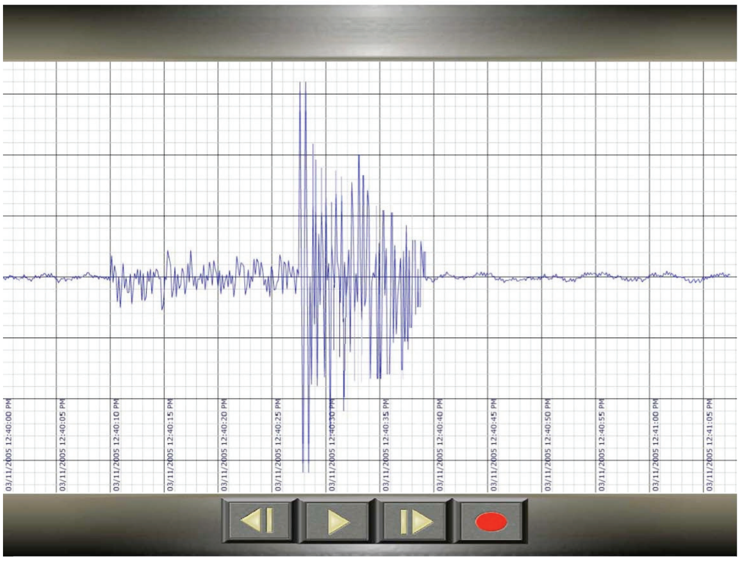
Within the domain of learning technologies, embedded phenomena draws from the traditions of constructivism and inquiry, especially as manifested in the use of technologies which put data capture and manipulation capabilities directly in the hands of learners. Early efforts with stationary "microcomputer-based laboratories" (e.g., Linn, et al., 1987; Tinker & Papert, 1989; Krajcik & Layman, 1993) was extended by the mobility of handheld computers through "probeware" (Soloway, et al., 1999) that allows students to capture and share data arising from real phenomena. A variety of learning environments have been built by researchers to help students learn subject matter by exploring simulated dynamic representations (e.g., DiSessa, 1977; Horwitz, Neumann, & Schwartz, 1996; Roschelle & Kaput, 1996). Virtual environments (e.g., Dede, et al., 1997; Windschitl & Winn, 2000) provided learners first-person access to data not directly accessible for reasons of time, space, safety, or scale. Embedded phenomena most directly draw inspiration from pioneering work in the connections between role-playing and non-desktop technologies (Resnick & Wilensky, 1997), especially the concept of participatory simulations (Colella, 2000; Wilensky & Stroup, 1999; Colella, 2000; Facer, et al., 2004; Rogers, et al., 2002), which use computational and display technologies in support of physical activity. Embedded phenomena extend the participatory simulation model by providing continuous, long-term representations of phenomena that run asynchronously ("things happen when they happen") with respect to the regular flow of instruction.

Method

Activity was situated within a unit on earth science in a diverse Midwestern U.S. self-contained fifth grade classroom of 23 students. As part of that unit, students experienced a series of 21 simulated earthquakes ("roomquakes"), each presumed to occur within the physical space of the classroom, over a period of six week. The simulation was effected by affixing four tablet computers to horizontal locations around the classroom; each computer served as a simulated seismograph upon which was depicted a continuously running strip chart recorder of ground vibration. Between events, the seismographs displayed simulated random noise; when a roomquake occurred, however, they traced out unique characteristic waveform (seismogram) corresponding to the expected vibration at their specific locations due to an event at a particular location in the classroom. (Roomquakes were also signaled by a low-frequency rumbling sound generated by a small subwoofer located in the corner of the classroom.)

With each event, students were responsible for determining the epicenter and (Richter) magnitude of the roomquake and for creating a record of the event. The locations of events were recorded by hanging Styrofoam balls from the classroom ceiling at their epicenters, color-coded to reflect the event magnitudes. Two other emerging data representations were also maintained using colored sticky dots on large wall posters: magnitude frequency distribution (the number of events of each of four magnitudes 4-7) and a timeline of the events. By reading the seismogram at each seismographic station, students were able to determine the magnitude of the event, and the distance of the event (in meters, rather than kilometers) from that station. (Earthquakes generate multiple waves that travel at different rates; the latency between arrival of two of those waves, P and S, is proportional to the distance of the event.) Magnitude can be determined by comparing event distance with graph amplitude. A reading from a single station, however, is insufficient to locate the epicenter, since it does not provide directional information. In order to obtain a solution, students needed to combine the distance information from multiple (at least three) stations through the process of trilateration.

In professional seismological practice, trilateration is performed through the process of determining the common point of intersection among three or more circles, requiring a level of mathematical sophistication beyond held by the learner group. Alternatively, it would be possible to use compasses and obtain a solution on paper, but we felt that this would unnecessarily add a layer of indirection, temporarily moving the activity locus from the classroom real estate to another medium. Instead, students used calibrated dry-lines anchored at each of the seismographic stations to sweep out arcs reflecting the locus of solutions from the individual stations until they found the location in the room where the endpoint of their measures coincided.



The learning goals of the earthquake simulation were focused in two areas: (1) the acquisition of skill in authentic seismological practice, including the determination of event distance and magnitude and the use of trilateration to determine event epicenters, and (2) an understanding of the distributional characteristics of earthquakes across the dimensions of space, intensity, and time, developed through student observation of the patterns reflected in the emerging historical record of events. Affective response to the unit centered on students' stances toward active investigation as an alternative to receiving information from teachers.

A task analysis of the activity resulted in the identification of 31 distinct *roles* that a student might perform in response to each simulated seismic event. Examples of individual roles included discrete interactions with the simulated seismographs (e.g., "count time between wave arrivals to determine event distance," "determine maximum amplitude of waveform"), physical actions necessary to effect trilateration (e.g., "pull calibrated string to correct distance," "hold moving end of string and sweep out arcs to find point of coincidence"), and data recording activities ("place colored dot on magnitude frequency distribution chart," "assist teacher in hanging Styrofoam ball from ceiling"). Among the 31 roles, 26 were associated with activity emanating from an individual seismographic station, while the remaining six were associated with a data recording activity, leading to a total of 109 (4x26+5) actions needed to respond to a single seismic event.

Data sources

Skill in seismological practice. Following the unit, students were individually interviewed and asked to demonstrate their ability to read seismograms, determine event magnitude and distance, and show the loci of potential epicenters for a hypothetical seismogram that they had not previously seen. Interviews were videotaped; student mastery was assessed on five discrete tasks (see Table 1) using a group consensus coding process. No pre-test was indicated; none of the students had any prior experience with the interpretation of seismograms.

Understanding of earthquake distribution patterns in space, time, and intensity. Over time, collections of earthquakes exhibit characteristic patterns in where they occur (along fault lines marking plate boundaries), when they occur (after-shocks follow large seismic events), and their magnitude (strong earthquakes are less frequent than mild earthquakes). We probed these understandings through a series of multiple-choice prompts using a written instrument that was administered prior to, and two weeks following, the instructional unit. The tests were also administered to another fifth-grade class that did not participate in a science unit on earthquakes.

Self-conception as investigative agent. Students were administered selected items from the TOSRA (Test of Science-Related Attitudes) Likert instrument (Fraser, 1981) in tandem with the distribution knowledge pre- and post-tests. The instrument was also applied to the control class.

Participation. Six video cameras were mounted on the ceiling of the classroom and oriented to capture detailed activity at the four seismographic stations as well as (wide-angle) activity in the center of the classroom. The cameras were activated for each of the 21 simulated earthquakes, and allowed us to track the activity of each individual student in the classroom. In the analysis below, we distinguish both the rate of participation and the variety of activities with which children engaged, in the belief that specialized practice in only some of the activities surrounding resolution of seismic event parameters are less likely to promote skill development and conceptual learning than an experience based on engagement in a fuller range of activity types.

Outcomes

Skill in seismological practice

Table 1 shows student mastery of the seismological practice skills of interpreting seismograms to determine event magnitude and the potential loci of event epicenters, as determined during the post-unit interview. Students were asked to perform the tasks sequentially, and incorrect responses were corrected by the interviewer after each task to avoid compounding errors. Most students mastered the basic skills associated with resolving seismic event parameters and determination of event loci; common difficulties centered on graph interpretation.

Table 1: Student post-activity demonstration of seismological practice skill,

Seismological skill	Mastery level assessed	Performance
Determine latency in wave arrivals	Within 3 seconds of actual latency	67%
Pull out dry line to proper length	Within 10% of actual length	78%
Demonstrate possible event loci	Draw string taut; sweeps out full circle	89%
Determine maximum graph amplitude	Within 10% of actual amplitude	72%
Use chart to determine event Richter magnitude	Correct magnitude	72%

Conceptual understanding of earthquake distributions

Table 2 shows pre-post differences in treatment and comparison groups' performance on multiple-choice items relating to the distribution of earthquakes in space, intensity, and time. Each item asked students to choose from among six possible responses.

Table 2: Student demonstration of understandings of earthquake distributions,

Distribution category	Performance on items relating to conceptual understandings of earthquake distributions					
	Treatment group			Non-treatment (control) group		
	Pre (N=22)	Post (N=24)	Change	Pre (N=22)	Post (N=21)	Change
Location	41%	88%	+47%	27%	43%	+16%
Magnitude	23%	63%	+40%	18%	24%	+6%
Time	41%	67%	+26%	32%	43%	+11%

Stances toward investigation vs. transmission of knowledge

Table 3 gives pre-post differences for selected items from the modified TOSRA exam. The treatment group showed positive trends toward a preference for investigation as on the four relevant items. In contrast, the non-treatment group trended away from an attitude as investigative agents and toward an authority model.

Table 3: Student attitudes toward science investigation

TOSRA Item	Likert score: (1=strongly disagree, 5=strongly agree)					
	Treatment group			Non-treatment group		
	Pre (N=22)	Post (N=24)	Change	Pre (N=22)	Post (N=21)	Change
I would rather find out why something happens by doing an experiment than by being told	3.95	4.17	+0.22	4.27	4.22	-0.05
I would rather do my own experiments instead of finding something out from a teacher	3.67	4.13	+0.46	3.91	3.73	-0.18
It is better to be told scientific facts than to find them out from experiments	2.14	2.04	-0.10	2.00	2.00	0.00
Doing experiments is not as good as finding out information from teachers	2.09	1.83	-0.22	1.72	1.91	+0.18

Participation

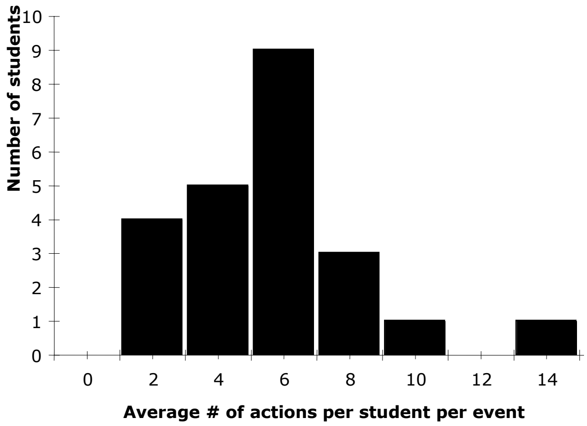


Figure 2. Distribution of participation: average roles per student per event over RoomQuake

By analyzing the videotape records of each event, we were able to identify which roles each individual student assumed for each event in the RoomQuake series. The histogram in Figure 2 shows the distribution of participation over the unit. Altogether, students averaged 5.6 actions per event, ranging from 1.3 (the least active student) to 13.6 (the most active student). An analysis of differential participation during the first and second halves of the instructional unit (Figure 3) shows that participation rates by individual remained fairly constant, although the extended time series did afford opportunities for a few initially hesitant participants to becomes substantially involved (the oval region in Figure 3) while at the same time exhausting the interest of some students who had initially been quite active (the rectangular region in Figure 3).

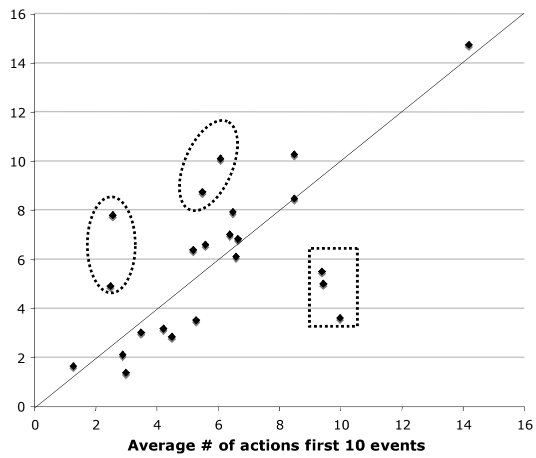


Figure 3. Participation rate in last 11 events as a function of participation rate in first 10 events. Points in the upper triangular area of the graph represent increased participation in second half of unit, with oval areas showing largest increases. The points boxed by the rectangle represent significantly decreased participation.

Beyond participation rate, these data also provide insight into the *diversity* of participation with respect to adoption of different roles during the intervention. On average, students adopted 25.2 of the 31 possible roles over the course of the unit, ranging from a minimum of 16 to a maximum of 29 distinct roles adopted. Figure 4 shows the distribution of role adoption across the entire class. Figure 5 shows a graph of the average cumulative unique roles assumed by students over the course of the 21 simulated seismic events. A logarithmic curve fitted to the time series of averages shows good agreement with the data; the model predicts that an additional 20 simulated events would be required to approach exhaustive assumption of every role by every child in the class.

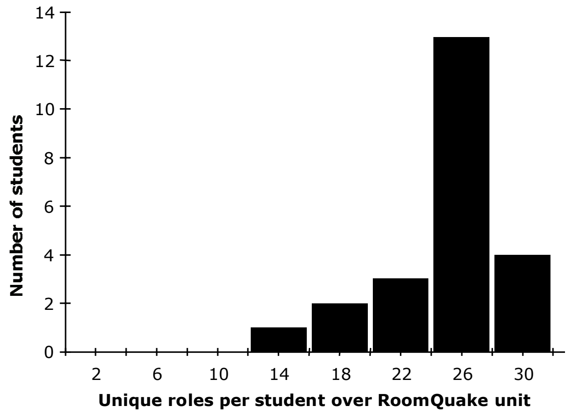


Figure 4. Distribution of student role adoption over Roomquake unit (number of distinct roles assumed per student).

The long series of activities afforded opportunities for students who were initially reluctant participants to expand the *variety* of activities in which they engaged. Figure 5 reveals that, on average, students had undertaken about half of the available roles by the fifth event. Figure 6 shows that students who assumed relatively few unique roles during the early stages of the unit used the additional time to expand their range of roles.

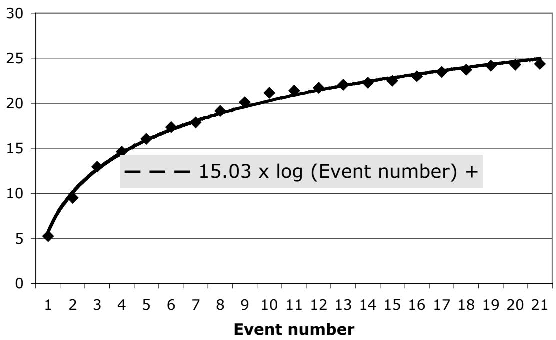


Figure 5. Average cumulative *unique* roles assumed as a function of event number.

The role of technology

How did these technology choices impact student experience? The design of the simulated instruments played a role; while it would have been easier for the students if we had presented simplified digital reports of event distance and magnitude, the use of the classical analog strip chart lent authenticity to their work. During the unit, the class engaged in a videoconference with a seismologist who showed them real-time seismograms from southern California that she was monitoring. The students were animated in their response, noting the similarity between the instruments that she and they shared, and asking detailed questions about the relationship between graph amplitude and event intensity. While the complexity of professional instrumentation runs the risk of overwhelming learners with tangential detail (Soloway, et al., 1994), attention to design elements that raise students' perceptions of the realism of the instruments may have significant impact on their view of the authenticity of their roles as investigators.

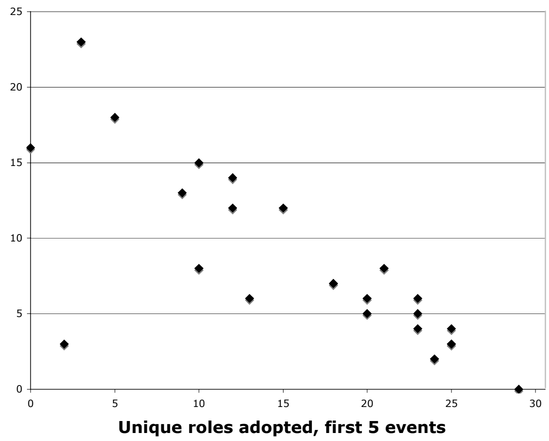


Figure 6. Role adoption during latter part of unit as function of role adoption during first 5 events.

The persistent representation of the simulated phenomena helped serve to maintain student interest over the long course of the unit and reinforce the real-time conceit of the simulation. In spite of the fact that for the vast majority of the time the seismographs showed only near-flatline behavior, students went out of their way to watch the displays during classroom breaks, and they established a habit of moving quickly to the seismographs when they first entered the classroom each morning to check for events that might have occurred overnight. While this approach comes at the cost of using computers dedicated to this single function for long stretches of time, we believe the benefit justified the expense.

Perhaps the most powerful feature of the RoomQuake technology was its use in delivering asynchronous events. Classrooms tend to be highly structured in their use of time, and the unpredictability of simulated seismic events introduced a tension that raised interest in the activity; students literally jumped out of their seats at the onset of roomquakes in their rush to get to the seismographs. Children ordinarily view class computers as passive devices, in that they respond only when the users initiate interaction; unlike adults, students do not typically computer event notices. Using the computer as a means to initiate activity, we believe, has significant potential as a more general strategy for motivating engagement.

Beyond the computers, the other “technologies” used in RoomQuake also played important functions. The measuring strings used to enact trilateration added to the sense of physical embodiment; while “messy” (the strings had to be strung over chairs and desks with kids having to playing “limbo” to move about), students found this aspect of the activity to be both fun and rewarding as they discovered the location of the event. The mapping of the virtual earthquake field onto the classroom space, we believe had value both in its promotion of a sense of local ownership, and in the sometimes amusing juxtaposition of locations between the two “spaces,” as when a roomquake occurred directly over the teacher’s desk.

The visible records of event histories via the Styrofoam balls hanging from the ceiling and the wall charts depicting accumulating event distributions also reinforced the locality of the phenomena, but more importantly helped to keep the thread of inquiry “visible” over a long time course in spite of students’ relatively infrequent direct interactions with the phenomena. We believe that dangling spheres in particular had considerably more salience than an information-equivalent version representation on paper or on a screen.

RoomQuake creates an environment for instruction and activity, but does not prescribe a specific instructional design. Since the study reported here, RoomQuake has been used in a half dozen elementary and middle school classrooms; in each instance, teachers crafted their own instructional variants of the unit. Some teachers compressed the time course of the unit, using fewer events. In classrooms with tall tin ceilings, teachers used tape-backed colored disks in place of Styrofoam balls. Different grade levels saw variations in learning goals, with middle school students, for example, focused much more strongly on the causal tectonics of earthquakes. While all employed the same technologies, no two instructional designs have been the same.

The distributed activity loci and range of actions gave kids choices, and the long time course gave them the opportunity to choose to participate on their own schedule. For some students, this was a very effective strategy, especially those children whose generalized reaction to engagement in classroom activities was focused on social interaction rather than meaning making. For other students, however, the design afforded too much freedom; some found it an easy way to avoid responsibility, while others found it difficult to assert their place within activity structure. Here, teachers played an especially important role, with some teachers intervening to ensure the participation of specific students on an ad hoc basis and other teachers explicitly rotating roles within work teams to ensure the distribution of participation.

Conclusion

Embedded phenomena such as RoomQuake physically situate inquiry physically within the simulated phenomena under investigation, and temporally within the regular instructional flow. The adaptations required by practitioners to incorporate such designs are substantial. This report provides tentative evidence that there may be significant learning benefits, to different kinds of learners, from adopting such a paradigm within, of course, the context of appropriate instructional designs. An additional contribution lies in the analysis of participation, which we believe offers a novel methodological lens for extending empirical descriptions of the growth of communities of practice (Barab, et al., 2002). In particular,

- The analysis of student performance in the areas of seismological practice and the understanding of the temporal, spatial, and intensity distributions of earthquakes provides evidence of learning in both domains, albeit with room for improvement. No comparison is yet offered relative to alternative instructional designs.
- The results of the affective (TOSRA) measures provide tentative support for the conjecture that practice can enhance students' self-conceptions as legitimized investigators, but that the recognition of the effort involved can negatively impact the desire to engage in practice.
- Preliminary evidence suggests that the rate of participation is uneven, but that the extended time course provided opportunities for at least some initially hesitant participants to move from the periphery to the center of the community of practice (Lave and Wenger, 1991). The propensity of students to adopt multiple roles over time, rather than specializing in a single role, arguably enriches the learning experience.

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