FIVE KEY CONSIDERATIONS FOR NETWORKING IN A HANDHELD-BASED MATHEMATICS CLASSROOM

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Handheld devices, most familiar to educators today in the form of graphing calculators, are rapidly improving their interface, computational, and communication capabilities. Communication capabilities allow participants to rapidly share mathematical objects among their handhelds, potentially contributing to improved classroom discourse. We have had the opportunity to explore the pedagogical uses of these new capabilities by extending our SimCalc technologies and curriculum with two significantly different forms of networked handheld computers. The contrast helps us to understand several pedagogically relevant distinctions among types of electronic communication. In this report, we describe list five key networking considerations and illustrate them with three classroom activities that have proven productive.

INTRODUCTION

Graphing calculators have become deeply integrated in the mathematics curriculum, supporting reform objectives, and allowing the NCTM to state that "technology is essential," without economically limiting reform to those schools that can afford computers (National Council of Teachers of Mathematics, 2000). Graphing calculators have succeeded by democratizing computation, but importantly, they also democratize access to powerful mathematical representations (Doerr & Zangor, 2000). The technology is continuing to evolve rapidly, featuring better displays, faster computation, and, importantly, new wireless communication options.

Mathematical discourse and communication is an important theme in research on mathematics learning (Cobb, Yackel, & McClain, 2002), and we expect that these new wireless, communication options for handheld devices will support pedagogy that engages students in classroom discourse more deeply. Indeed, a growing community of researchers (Stroup et al., 2002) has written about the potential of new classroom networks to improve classroom learning, and an PME-NA discussion group has been formed on this topic. The discussion group met in October 2002 and identified wide ranging uses and possible benefits of the technology (see Davis, 2002; Kaput, 2002; Owens, Demana, & Abrahamson, 2002; Roschelle & Pea, 2002; Wilensky & Stroup, 2000). The discussion at the 2002 conference drew a large audience, and raised as its most significant issue the question of understanding succinctly what functionalities new classroom networks offer, and how those functionalities support pedagogy.

In this report, we seek to respond by describing five key classroom networking considerations. To serve the interests of the PME audience, we seek to focus only on those aspects of networking that are most pedagogically relevant. To judge pedagogical relevance, we have drawn upon our joint research with SimCalc software and curriculum in networked classrooms with two remarkably different technical configurations. Moreover, throughout our effort, we have also kept abreast of related projects (e.g., in the PME-NA Discussion Group).

Our account here is descriptive, seeking to summarize networking considerations that have become increasingly prominent in our research as we have observed classrooms over two years of experimentation, data collection, analysis, and research discussion. After briefly orienting readers to the SimCalc Project, we describe three pedagogical activities that have been repeatedly successful in our classroom field sites. We use these to draw out five key design considerations that relate communication infrastructure and pedagogy. Reports in preparation and existing publications describe more extensively the design tensions (Tatar, Roschelle, & Vahey, submitted), curriculum research (Hegedus & Kaput, 2001; Kaput, 2002), and classroom outcomes in our classroom experiments.

THE SIMCALC PROJECT

For the last decade, the SimCalc Project has focused on increasing students' ability to learn the mathematics of change. Through iterative design experiments, we have developed an approach to the concepts of rate and accumulation that builds upon piecewise functions, expressed in position and velocity graphs that students can directly manipulate, and motion simulations that result from the graphs (Roschelle, Kaput, & Stroup, 2000). Our curricula and software have been successful used with students in a wide variety of middle school, high school, and university settings.

In our recent work (supported by National Science Foundation grant #0087771), the SimCalc Project has focused on handheld devices in order to provide access to our software in more classrooms. TI-83+ graphing calculators have been a primary target, because of their availability in American high school mathematics classes. In addition, we have explored color Palm OS devices, to gain a better sense of what future handhelds (with better displays and stylus-based interaction) might offer. As we will discuss below, the TI and Palm products offer very different styles of networking. Thus we have two teams using roughly the same representations and curriculum with different devices and networks. The contrast between our devices and settings makes the relevant pedagogical distinctions among networking capabilities more evident.

ILLUSTRATIVE ACTIVITY STRUCTURES

Major classroom benefits of networked handhelds are mediated by the forms of activity in which they are used. Hence, we illustrate how the considerations we have discussed above play out in classrooms by discussing three of our most successful activity types.

The Exciting Sack Race

In the "exciting sack race", students create both a position graph for a character who is racing alongside a given second character and a narrative story for the race. The story and graph are supposed to be as exciting as possible. Typically students make races in which their character is ahead, then falls behind (perhaps even going backwards or stopping), eventually catching up and ending in a tie.

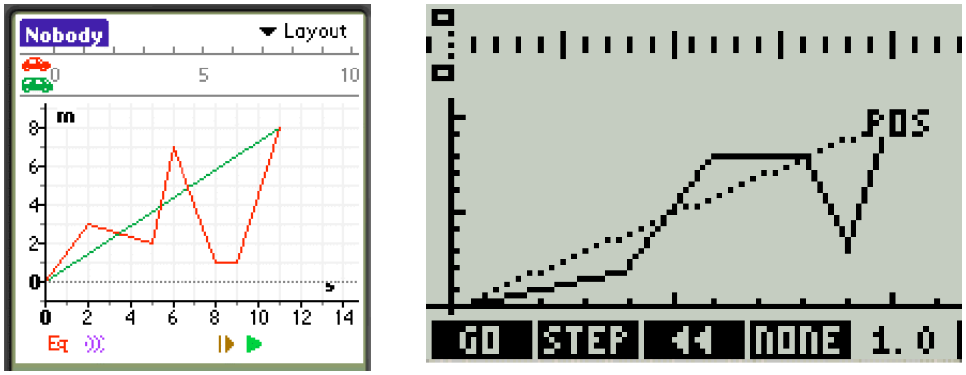

Figure 1: Exciting Sack Race on Palm (left) and TI (right).

The exciting sack race works well on both technologies (Figure 1). The communicative infrastructure is primarily used to distribute an initial setup and then collect each student's race. Collection on the TI is accomplished by "grabbing" a single student's work for display on the teacher's public display. In contrast, "collection" in the Palm classroom is a matter of asking a student to walk to the single classroom projector and place their Palm under it. It is important that students can keep their story private until they are ready to share it, although the eventual sharing is not anonymous. In some variants, students exchange stories (via paper) and then create a new graph that fits the story. They can then compare different graphs that fit the same story.

We have observed that this activity engages students in exploring slope-as-rate (e.g. how to make a position graph in which a character "catches up", "stops", or "goes backward"). With the right teacher provocation, it can also lead to improvement of mathematical description of the features of graphs (e.g. "negative slope" not "bends down"). Every time we have used this activity structure, it has proved exciting and engaging for the students. In fact, in each of the four Palm classrooms, at least one student has literally jumped up and down and called others to come over and look when he or she discovered that negative slope meant that the simulation moved backwards.

Match My Graph

In Match My Graph, one student ("checker") makes a hidden mathematical function describing a motion (e.g. a linear function). A second student ("guesser") contributes a function to the first student, constituting their guess. The checker then provides a verbal clue to the guesser, explaining how the two functions are different (e.g. "your slope is too steep"). The guesser than makes a revised guess and resubmits. The students iterate until the functions are the same. Then they exchange roles. Match My Graph may be played in many variations: different function or graph types may be used; the guesser and checker may see different representations; the checker may only see the guesser's motion, without a corresponding graph.

We have done this activity with both Palm and TI technology. On the Palm, student-student beaming is used to contribute a guess, which is collected for comparison as an overlay on the same Cartesian plot. The teacher may distribute sample language for clue via a big piece of paper posted at the front of the class, and clues are communicated socially. On the TI, cables are used to contribute guesses to the linked machine.

A key functionality of the technology in both cases is to keep some information (i.e., the hidden function) private, while facilitating comparison within a single graph. The technology's support of multiple representations is also key: in some Match My Graph challenges, the guesser submits their function using a position graph but the checker compares the function using its corresponding derivative on a velocity graph. This forces students to use mathematical language based on how velocity and position functions relate rather than superficial features of graphs. One striking difference is in the differences in the communications infrastructure supported by the different technologies. Because a physical cable links the calculators, the activity must occur in dyads, and the groups are not easily malleable. In contrast, the beaming communication of the Palm handhelds allows any number of guessers, in a variety of configurations.

In our analysis of Match My Graph classroom activities, we have seen students who are highly motivated to solve the puzzle grapple with language, and sometimes become frustrated at the ambiguity of everyday expressions when attempting to describe a mathematical situation. Through the introduction of a set of mathematically defined "clues" students begin to see the relevance of mathematically precise language. Although we do not expect students to adopt mathematically correct language immediately, they do begin to appreciate more precise language, and begin to adopt mathematical language in the creation of a bridging language (Herbel-Eisenmann, 2002).

Aggregation of Parametrically Varying Functions

In this class of activity, the teacher asks every student to construct a mathematical object with one or more common properties (e.g., make a line that intersects the point 6,3). Further, each student may be given a unique parameter (e.g. one student is assigned a y-intercept of 1, another is assigned 2, etc.). The students build their functions, and then contribute them to a central location. The contributions are aggregated on one coordinate system (Kaput & Hegedus, 2002).

We have only tried Parametric Variation as a whole class activity using the TI technology, as it is best supported a network that reaches the whole classroom. (We also plan to try it in March 2003 on Palm technology, with four students submitting functions to a fifth Palm which will show all four contributed functions.) A powerful way to integrate social and mathematical structures (c.f. Stroup et al., 2002) is to break the class into numbered groups and have each student count off within their group, yielding 2 numbers that can be used as unique "personal" parameters for each student.

In classroom experiences, we have noted many virtues of the parametric variation activity. It engages all students, as each is responsible for making a contribution. The teacher can easily see if some students are not participating, creating an environment of accountability and high attention. Further, the aggregated result quickly reveals if any student missed the mark; with most functions passing through a single point, any functions that do not satisfy the requirement are visually obvious. But most importantly, the aggregate becomes an important mathematical object in its own right, and a source of classroom discussions. Students can be asked to describe how their value of the slope co-varied with their y-intercept (e.g. increasing y-intercepts required decreasing slopes) and to reason about which lines had positive vs. negative slope. As an advanced exercise, they can be asked to write a single parametric equation that models all the lines.

COMMUNICATION AND PEDAGOGY

We now consider at a somewhat more abstract level how the communication infrastructure used in these classroom activities relates to pedagogy.

Consideration 1: Network Extent and Generality

Networks are usually used to enable students to connect to *resources outside the school*. In contrast, the activities we have focused on *within-class* networks that exchange mathematical objects among students and the teacher. The extent and generality of the network infrastructure brought into a classroom has fairly dramatic pedagogical consequences because it intimately interacts with learning and teaching.

For example, the Internet is currently the most common computer networking communication platform. The Internet is a general purpose form of networking: it supports interactions from any device to any other device worldwide, and is agnostic with regards to the content and types of exchanges. The news media has amply documented the potential dangers of bringing the full generality of the Internet into the classroom: students can be distracted by email and instant messaging; they can view undesirable content; they can use the technology to cheat (Pownell & Bailey, 2001).

The within-classroom networks we have explored exchange messages only within a classroom; these networks are not general-purpose and do not support email, instant messaging or web browsing. Classroom communication centers on the exchange of mathematical functions and their manipulation. In our scenarios, most mathematical content discussed in the classroom is created within the classroom, and shared among participants in ways strongly tied to pedagogical purposes; we have observed little disruptive use of the network.

Consideration 2: Network Topology

A major design distinction among within-classroom networks is in the messaging topology supported. TI Navigator[1] primarily supports a *hub and spoke* topology, where all student messages travel ONLY to and from the teacher hub. Indeed, communication flows in TI Navigator are primarily teacher-initiated (the teacher "grabs" student constructions or "broadcasts" a starting point to all students), which encourages network communication to follow a conventional call-and-response cycle. The Palm product[2] supports a neighbor-to-neighbor topology. Using beaming, students can communicate only with their spatial neighbors at a time of their choosing. Consequently, the TI product naturally supports teacher-led synchronized full class interactions, along the lines of a conventional call and response cycle. The Palm topology better supports dyadic and small group interactions, enabling different groups to proceed at their own rates. However, a teacher using Palms can distribute something to the whole class by purchasing special broadcasting hardware and software, or via a cascade, in which she seeds a few students, who pass it on to a few more students.

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[1] See http://education.ti.com/us/product/tech/navigator/features/features.html for product information.

[2] See http://www.palm.com/education/ for education-related product information.

We have noted that a benefit of both of these topologies is that it is easy for the student to decide *where* to send a message. A Palm user points the device at the recipient. A TI user always sends only to the teacher or to the partner connected with a physical cable, so no selection is needed. A topology that matches the structure of typical classroom exchanges is thus a powerful simplification.

Consideration 3: Anonymity and Group Display

The above topologies differ in their implications for how and when information travels from private to public. Neighbor-to-neighbor beaming more naturally leads to an identification of an idea with a person. Hub-and-spoke designs allow the student's contribution to the whole to remain anonymous when desired. In situations where students feel vulnerable, anonymity can be crucial in helping students risk answers without being singled-out (Davis, 2002; Owens et al., 2002). However, when discourse is to be mediated by the students themselves, detailed knowledge of the position held by the other may be required and beneficial.

A related pedagogical issue is the use of a public display; usually a LCD projector driven by a computer that is connected to the classroom network. A public display can be used for teacher demonstrations, to feature or compare students' work, to show aggregated work (as described above), and for displaying the results of instant polls and quizzes. Participatory simulations (Wilensky & Stroup, 2000) and formative assessments (Owens et al., 2002) particularly rely on a public display which becomes the center of attention; the main purpose of the handhelds is to provide input to the public display. On the other hand, many successful peer and small group activities do not require a central classroom display, which is worth noting since LCD projectors are costly and not generally available in classrooms.

Anonymity and the group display, under control of the teacher, interact in subtle but important ways. In actuality, all students may log in and the teacher may be able to determine exactly who contributed what. Nonetheless, it can be beneficial to avoid labeling individual students' contribution in the public display so that students focus on the mathematics rather than who produced it. In other cases, personal identification with a publicly displayed object can generate strikingly intense student attention and make classroom discussions very fruitful.

Consideration 4: Types of Network Functions

We have found it useful in our classroom experiments to think about the network as accomplishing pedagogically useful transformations of the data available throughout the classroom, instead of merely sending or receiving this or that. The network operations we have found pedagogically useful include:

- *Distribute*: Sending the same starting document to every student (TI, Palm).
- *Differentiate*: Sending different parameter settings to each student, in a systematic pattern (TI).
- *Contribute*: Transmitting a mathematical function or data point constructed by a student to a peer or the teacher (TI, Palm).
- *Collect*: Forming a group of related but distinct functions or data constructed by multiple students; often viewed as side by side contrasts (TI, Palm).

- *Aggregate*: Combining related functions or data into a single overall construction, often then displayed publicly, with or without anonymity (TI).

Two additional network operations would be useful, but are hard to implement on the technology available to us:

- *Look:* It would be useful to a teacher to capture a view from a student's screen without disrupting the student, for example while walking around the classroom
- *Exchange:* Swapping information so as to continue to the next step of a symmetrical process, for example grading each other's work.

Consideration 5: Features of Representational Integration

Finally, it is crucial to the pedagogical uses we have found for classroom networks that communication and representational functions are tightly integrated. Generally speaking, students contribute mathematical functions or points via the network, and these become visible within graphs or other representations. We have found it pedagogically useful to manipulate how transmitted functions become visible in a receiver's display. For example, a function, f, constructed as a position graph on one handheld may show up as f' in a velocity graph on another, requiring students to think about their relationship. Further, it is sometimes crucial to hide transmitted data from the student, so a "secret" can be passed from machine to machine, and only revealed when guessed by another student. Finally, some activities group students by the kind of contribution they are asked to make; it is then useful to layer contributions by the identity of the group.

CONCLUSION

Classroom networking is still at an early stage of exploration, so it is not yet possible to say what the most important uses of classroom networks in a mathematics classroom will be or what the relationship between special and general purpose classroom configurations will be. Further, available networks differ markedly in their capabilities, supporting widely different participation structures. It will take the efforts of many researchers over an extended time to tease out the best practices and uses of these new capabilities, and how varied goals and purposes can be integrated for practical use in the classroom. The five key considerations in classroom communication infrastructure have had high pedagogical relevance in our studies. By attending to these considerations, researchers may more clearly explore the emerging design space for improving classroom discourse.

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