DOCUMENT RESUME

ED 464 830 SE 066 114

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TITLE An Exploratory Study of the Implementation of an Interactive Learning System in Two Eighth Grade Mathematics Classes.

PUB DATE 2002-04-00

NOTE 20p.; Paper presented at the Annual Meeting of the American Educational Research Association (New Orleans, LA, April 1-5, 2002). Some charts may not reproduce well.

PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.

DESCRIPTORS Cognitive Style; *Computer Uses in Education; *Grade 8; Interaction; Junior High Schools; Mathematics Education; Teaching Styles

ABSTRACT

During the last decade, U.S. K-12 schools have approximately tripled their spending on increasingly powerful computers, expanded network access, and novel computer applications. The number of questions being asked by educators, policymakers, and the general public about the extent to which these technologies are being used in classrooms, for what purposes, and to what effects, has likewise increased. Recent research is characterized by an awareness that the process of implementing educational technologies in schools is much more human than technological and can only be understood in context. Exploring the human implementation process is thought to be one key to understanding how educational technologies find purchase and evolve in local classroom environments. This naturalistic inquiry explored the semester-long process of implementing an interactive learning system in two math classes in a rural mid-Atlantic Junior-Senior High School. Schwab's (1978) curriculum contexts (teacher, student, subject matter, milieux) provided loci for identifying, describing, and interpreting the students' and teacher's experiences of the interactive learning system. Data collection was based on field observations, periodic interviews with individual students and their teacher, exploratory and culminating focus group interviews with students, and document analysis. Grounded theory methods were used to analyze the data. It was concluded that there was no significant change in the teacher's instructional model during her implementation of the interactive learning system. Conditions that supported the teacher in her decision to adopt the educational technology curriculum innovation did not sustain her instructional evolution during the implementation process. The teacher reached a point of implementation impasse while simultaneously using the traditional district-controlled, teacher-proof curriculum and the interactive learning system with her two eighth grade math classes. The level of mismatch between the traditional math curriculum and the curriculum represented by the novel educational technology emerged as a critical factor influencing the implementation process. The students' primary implementation experiences focused on learner-control via the tools of the system, opportunities for spontaneous peer interactions, and increased motivation in the technology-enhanced math class. Recommendations for future research and for the implementation of educational technologies in schools are provided. (Contains 35 references, 3 tables, and 2 figures.) (Author/MM)

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in Two Eighth Grade Mathematics Classes

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During the last decade US K-12 schools have approximately tripled their spending on increasingly powerful computers, expanded network access, and novel computer applications. At the same time, there has been a corresponding increase in the number of questions being asked by educators, policymakers, and the general public about the extent to which students are using these educational technologies, for what purposes, and to what effects. The value of this research is premised on the researcher's assumption that exploring the human implementation process is one key to understanding how educational technologies find purchase and evolve in local classroom environments. This naturalistic inquiry explored students' and their teacher's classroom experiences during the semester-long process of implementing an interactive learning system, Destination Math (DM), in two eighth-grade math classes in a rural mid-Atlantic Junior–Senior High School. Data collection was based on field observations prior to and during the implementation process, focus group interviews with students, semi-structured interviews with students and their teacher, and document analysis. Grounded theory methods were used to analyze the data. The findings show that while the teacher's instructional practices did not change during the implementation process, students' learning experiences changed significantly. The teacher's lack of instructional change in the DM class can be explained by the difficulty of: simultaneously implementing two diametrically opposed math curricula, reskilling without support, and aligning her use of the curriculum innovation with management controls on instruction. For the eighth grade students, the educational technology innovation afforded opportunities to assume instructional roles they did not hold in the regular math class. Students used the interactive learning system to make instructional decisions regarding the content (what) and delivery (how) of math concepts presented in their DM class. Students spoke positively about the level of instructional control afforded to them vis-à-vis math activities, representation of math content and the social context for these activities: the opportunity to interact with their peers, in the DM math class. Given these three opportunities for students to leverage instructional agency when using the interactive learning system, students reported increased interest in math in the DM class, compared with students in the regular math class. Researcher observations supported students' self-reports: students' engagement with math, operationally defined as time-on-task, increased in the DM class. These findings suggest that, while instructional change may be a complex one for teachers, given the classroom implementation of novel educational technologies, these instructional tools may leverage significant changes in students' instructional roles in the classroom. When used to increase students' instructional agency in the learning environment, novel educational technologies may increase students' interest in subject matter and their engagement in learning.

Introduction

Increasingly powerful computers, expanded network access, and novel computer applications have enlarged both investments in, and expectations for, the transformation of teachers' and students' classroom learning experiences. During the last decade US K-12 schools have approximately tripled their spending on educational technologies (Quality Education Data [QED], 1999). However, while investments in educational technologies have steadily increased, not enough money has been spent on educational research to determine how these investments shape classroom practices (Web Based Education Commission, 2000; Shaw, 2000). Merely because curriculum producers are making software and their school customers are acquiring their products and the hardware to allow them to be used, does not tell us how, or to what extent, the daily lives of typical school children and their teachers are being affected or changed by these educational technologies (Becker, 1998, p. 20). The present research was designed to enliven and enlighten current discussion of student and teacher-use of educational technologies, by exploring the implementation of an educational technology in two eighth grade math classes, during the Spring semester 2001.

This research represents a departure from the early research on educational technologies (1970s and 1980s) which emphasized the learning outcomes value-added model: the decontextualized, cognitive-psychological approach to researching the interaction of individual students with computers. These early studies looked so specifically at particular technologies and their impact on single students, that they contributed little to the larger, more challenging project of understanding the roles that technologies can play in addressing the key challenges of learning in classroom contexts. Recent research on educational technologies is characterized by an awareness that the impact of technology on specific aspects of teaching and learning can be "usefully understood only in context" (McMillan Culp, Hawkins, and Honey, 1999, p. 8). Educational technologies alone do not translate into improved instructional outcomes: They matter only when harnessed for particular ends in the social context of classrooms; they must therefore be studied in these contexts. The regular math class, and the DM class, represented the contexts for this naturalistic inquiry. Throughout this fourteen-week study, the focus of the research was on the experiences of both the students and their teacher with the interactive learning system within the curricular and pedagogical contexts of their math classes. The main research question asked: How is an interactive learning system for math implemented in two eighth grade math classes? Supporting questions asked: How do students experience the interactive learning system over time? How does the teacher experience the interactive learning system over time? These questions were operationalized by asking the more informal question: What do students and their teacher *do*, *say,* and *make* in the research context?

Research Context

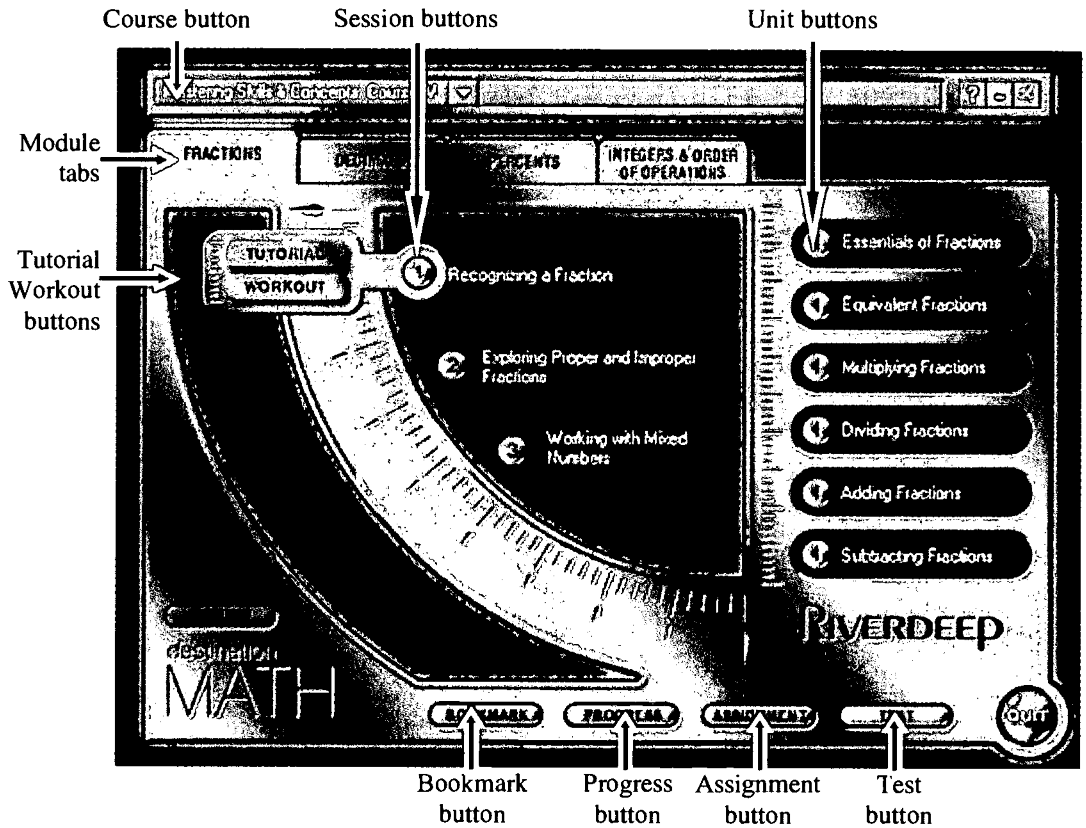
Participants

Participants in this study included one teacher and 32 students (14 and 18) in two lower-level eighth grade math classes. This research began in the regular math class four weeks prior to the implementation of the interactive learning system and continued during the following ten weeks. Qualitative methods were used to explore the process of implementing the interactive learning system, DM, that was used twice weekly, during students' regularly scheduled (40 minute) math period in the computer lab on Wednesdays and on Thursdays. On alternate days, students and their teacher used the "highly structured" and "highly prescriptive" (Saxon, 2001) text-based math lessons, provided in the district-adopted math curriculum.

Materials

RVDP was founded in Ireland in December 1995 as a developer and provider of technology-based educational solutions for the United States kindergarten through high school, or K-12, market. RVDP offers Internet and CD-ROM based comprehensive courseware and supplemental curricula in math, science, and language arts.

Figure 1. DM Main Menu Screen (Course IV)



In November 2000, the Westridge school district purchased licenses for use of the Riverdeep interactive learning products by all eighth grade students and their teachers, intentionally targeting improvement of students' math skills. RVDP curriculum products for middle school math include *Destination Math* (DM), a comprehensive math program designed to supplement or replace traditional math curricula, and *Tangible Math* (TM), a simulation-based math program, which focuses on the development of students' problem solving and analytical skills. In the present study, the teacher chose to implement the DM component of the RVDP suite of learning resources with both of her eighth grade math classes. DM comprises five math courses organized in two series or curricula for students in grades four to twelve. Participants in this study used DM Course IV, Mastering Skills and Concepts.

Figure 1 presents the structure of DM Course IV, used by students in this study. The course is composed of four *modules*: Fractions, Decimals, Percents, and Integers and Order of Operations, each representing a major topic in the eighth grade math curriculum. Each DM module is further broken down into *units*, which address specific learning objectives and are correlated with state and national standards for mathematics learning. The teacher management system for DM contains a bank of test items that are correlated with specific learning objectives and organized by unit. Unit buttons for the fractions module are visible to the right of the user's screen in Figure 1. DM units are further divided into three *sessions*. The user enters DM at the session level.

Each DM session comprises a *tutorial* and a *workout*. The user may also access a tutorial or workout as a system-generated *prescribed assignment*, based on the level of mastery of learning objectives demonstrated by the user on assigned tests. From the main menu, DM users may choose to work on a teacher-assigned test, a tutorial, or a workout. During their ten-week use of DM in their math classes at Westridge, students were instructed to complete teacher-assigned DM tests, prescribed assignments, and any additional activities for each unit before proceeding to the next unit.

Data Collection

Participant Observation

Participant observation strategies (observation and conversation) enabled me to take an active role in experiencing and enquiring about the teacher and her students' uses of DM in their math classes (Wolcott, 1999). During the four weeks prior to the implementation of the interactive learning system, I gathered background data by observing the regular math class and conversing with students and their teacher during lunch break, class transition times, and before and after school. Both participant observation strategies enabled me to build rapport with students and their teacher and obtain information about the context for students' math learning in an unobtrusive manner. In the initial weeks of this study, I focused my observations by detailing elements of the classroom and computer lab environments (classroom map protocol) and describing the activities of students therein (activity framework protocol). I recorded students' talk within the DM math class using a small pocket recorder. Analytically generative data included both prompted and unprompted verbal episodes within the DM class. The former included student think-alouds while using DM and student responses to researcher questions. The latter included individual students' verbal responses to DM and students' conversations with peers and/or their teacher. Written descriptions of participants' coverbal behaviors (expressions, gestures, actions) in their math classes informed and extended students' voice-recorded data. Combined with classroom observations, unscheduled verbal exchanges with students provided valuable opportunities for me to become familiar with "the native communicative repertoire" of participants in the eighth grade math class (Briggs, 1984, p. 24). These classroom conversations provided crucial information on the interaction between the eighth grade students' talk during scheduled math time and their social and cultural norms and patterns of interaction in the math class. Ongoing conversations with students informed the development of semi-structured interview guides throughout the data collection process.

Interviewing

Semi-Structured Interviews

I used Patton's (1990) "general interview guide approach" (p. 280) to plan periodic semi-structured interviews with individual students and their teacher. These interview guides were developed and sequenced using Spradley's (1979) ethnographic questions, the third element in his ethnographic interview (p. 58-68). I planned three phases of semi-structured interviews (exploratory, intermediate, culminating) with the eighth grade math teacher during this fourteen-week research study. The exploratory teacher interview was scheduled in week one, three weeks prior to the teacher's implementation of DM and was designed to explore the class teacher's past experiences with math and technology and, in particular, her motivations for implementing DM in her math classes. The purpose of the second teacher interview, scheduled in week nine, was to explore the teacher's own uses and perceptions of DM within the math class. The culminating interview with the math teacher was scheduled in week 14, the final week of this study, and was planned as an active interview, one that could "acknowledge interviewers' and respondents' constitutive contributions and consciously and unconsciously incorporate them into the production and analysis of interview data" (Holstein & Gubrium, 1995, p.4). The purpose of this final interview was to discuss the teacher's reflections on, and my interpretations of, her own use and her students' use of DM in the math class.

Two semi-structured interviews were scheduled with individual students during weeks 10 and 14 of this research study. I used naturalistic sampling (Ball, 1990) to select four students for semi-structured interviews "to generate the information upon which the emergent design and grounded theory can be based" (Lincoln and Guba, 1985, p. 201). Combined with classroom conversations and observations, these individual interviews enabled me to construct portraits (Lawrence-Lightfoot and Hoffman, 1997) or mini-embedded case studies of four students in the teacher's eighth grade math classes (two students from each class). For example, in the first semi-structured interview with students, I asked each student to tell me what he or she thought about math. Many students had frequently expressed their dislike of math within the regular class. The semi-structured interviews with these four students afforded opportunities for me to explore in greater detail phenomena such as student dislike of math emergent in the larger class picture. In this way, each individual student portrait served as a rhetorical device, providing vivid renditions of broadly observable patterns of class behavior, thereby directing and redirecting the most fruitful path of research in answering the research questions. These four richly detailed student portraits, grounded in conversation and interview data, facilitated "the on-going joint collection and analysis of data associated with the generation of theory" (Glaser and Strauss, 1967, p. 48).

Focus-Group Interviews

I scheduled exploratory and culminating focus group interviews with students to further explore their experiences with educational technologies and math in general and with DM in particular. Flick (1998) suggested the four processes or elements of group discussions that I used to structure the focus group interview guide: brief explanation of the research procedure, preparation for the discussion, discussion stimulus, and process discussion (p. 119-120). I held exploratory focus group interviews with students to probe their prior experiences with educational technologies at home and in school, their attitudes toward math, and their expectations for the DM learning system. Culminating focus group sessions in the final week of this research offered opportunities for respondent validation or member checking of my own interpretations of students' experiences with DM in their math class.

<u>Document Analysis</u>

To further extend my understanding of participants' experiences prior to and during the implementation process, I analyzed text documents gathered from the research setting (Glesne and Peshkin, 1992) using a document analysis protocol. Documents I collected and analyzed included a printed copy of the school mission, the Saxon math texts, students' homework assignments, DM test reports, DM progress reports, and so forth.

Data Analysis

Given the documented need for new, theoretically expressed understandings of students' and teachers' experiences of the classroom implementation of educational technologies, I chose to analyze my transcribed research data (classroom observations, classroom conversations, interviews) and related documents, using grounded theory methods. "The value of the methodology... lies in its ability not only to generate theory but also to ground that theory in data" (Strauss and Corbin, 1998, p. 8). I proceeded from description to conceptual ordering and theorizing (three activities foundational to Strauss and Corbin's theory building process), by iteratively coding transcribed data regarding students' activities in their math class. Strauss and Corbin (1990) explained that coding is "the process of analyzing data" (1990, p. 61) in order to create theory from data.

I developed a systematic three-step process for coding all transcribed data. To generate initial categories and to discover relationships between these categories, I began by coding transcribed exploratory interviews and

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classroom conversations by hand, using participants' own words (in vivo codes) when possible. I then record coded data electronically using the qualitative data analysis software, *N.5*. In parallel with my use of *N.5* to code transcribed data (line-by-line and open coding), I employed the concept-mapping software program, *Inspiration*, to explore relationships within and between concepts evident in the data (axial coding). The multiple representational methods for linking categories, which Inspiration afforded, supported development and refinement of my emerging grounded theory (selective and focused coding) of students' experiences with DM in their math class.

Flick (1998) noted that this combination of multiple methodological practices in a single study is best understood as "a strategy that adds rigor, breadth, complexity, richness, and depth to any inquiry" (p. 231). I employed these methods of data collection and analysis to secure an in-depth and richly triangulated understanding of students' experiences with an interactive learning system in their math class. Maxwell's (1992) five kinds of understanding and validity in qualitative research (descriptive, interpretive, theoretical, generalizability and evaluative) were used to guide all phases of data collection and data analysis.

Results and Discussion

Teacher's Implementation Experiences

When the Westridge School District administration decided to increase the Junior-Senior High School's investment in educational technologies, an instructional technology already existed in Mrs. Hall's eighth grade math class. This text-based technology was standards-aligned and teacher-driven. Mrs. Hall used the district-mandated Saxon math scheme to teach each of her daily math classes. The common tools used in Mrs. Hall's math lesson were the textbook, blackboard, and worksheet. These tools were used in combination to support teacher lecture and student seatwork during this teacher's eighth grade math classes. Mrs. Hall chose to implement the most highly-structured math component of the RVDP system, DM. Mrs. Hall's initial use of the system replicated her typical pattern of instruction in the regular math class. Just as Mrs. Hall assigned her students to independent study-top desks in her own classroom, she consistently assigned one computer to each student for the duration of her ten-week implementation of DM in the Gateway lab. Mrs. Hall did not use DM to teach new math concepts to students, but rather to test and reinforce math concepts previously taught to students using the regular (Saxon) math scheme "What we've been using it for is basically reinforcement. I looked at what I was already doing... I just thought well, they've had some background in each of those things, so I chose those".

Why did Mrs. Hall's instruction not evolve beyond the level of Adoption (Sandholz et al., 1997) of the RVDP educational technology? I provide three interpretations of the lack of teacher instructional change during the implementation process. These are not inconsistent with one another. Taken together, the three explanations aim to do justice to the complex human experience of instructional change, given this snapshot of one teacher's fourteen-week change experience.

Reskilling Without Support

In the present study, Mrs. Hall cited her lack of experience with the RVDP system as one significant impediment to her understanding and use of these resources to teach math. In their research of technology-adopting teachers, Sandholz, Ringstaff and Dwyer (1997) noted that given teachers' lack of experience with the educational technology, they attempted to blend its use into the most familiar form of classroom practice- direct instruction. Few opportunities were provided for this teacher to experience the RVDP learning resources. Mrs. Hall first used the RVDP learning system with the RVDP implementation specialist for South Central Pennsylvania during a three-hour professional development session for all eighth grade math teachers. Following this professional development experience Mrs. Hall decided to implement the RVDP resources with her eighth grade students five weeks later, during the Spring semester 2001. The other eighth grade teacher chose to delay her implementation of the RVDP resources until the Fall semester 2001. While this one professional development experience was sufficient to prompt Mrs. Hall to implement the DM curriculum innovation in her eight grade math classes, her anxiety concerning her impending implementation was evident in the two weeks prior to her first use of DM with students: "I'm excited but a little apprehensive, just because you don't know what to expect when you try something new. And you worry...". The supportive conditions (allocation of time, development of knowledge) provided to Mrs. Hall during her three-hour inservice were not sustained during her implementation of DM. She explained:

> The in-service provided by Eileen (Riverdeep Implementation Specialist), was short, just a few hours in one evening... But that kind of happens, you know, sometimes you get in serviced, and then there's a big lull in time until you have to use it. And then you don't really remember what you did learn, you know to try to apply it. If you don't use it right away.

Paradoxically, Mrs. Hall was to teach students how to use the RVDP innovation without first having learned to use it herself. Mrs. Hall's desire for in-school professional development opportunities to assist her in implementing DM was evident during this 14-week implementation. The two factors most frequently cited by Mrs. Hall as impeding her implementation of the RVDP resources were lack of knowledge of the innovation, and lack of time to explore the innovation.

> See, I didn't have that much time to look at the lesson plans that were available, the handouts that were available, that you might want to [pause] in your classroom, use those kinds of things, to either extend a lesson there or maybe even introduce a lesson in that way here before you would go use it. So I would like to have had the time to get into that aspect of it.

The resources available to Mrs. Hall during this implementation process, technical support and on-line and text-based RVDP teaching resources (user manual, activity notebook), were rarely utilized by her. Sustained professional development opportunities, would have targeted support to Mrs. Hall's particular needs and concerns during this implementation process, thereby increasing her access to the RVDP suite of instructional tools and resources. This research suggests that the success of a teacher's implementation of a curriculum innovation may be determined by the scope and extent of the professional development opportunities provided to him/her during the implementation process.

Simultaneous Implementation of Oppositional Curricula

Following Roger's (1995) analysis, although Mrs. Hall entered the implementation process with high Awareness Knowledge of the RVDP math resources, her Principles Knowledge, and How-to Knowledge were limited. This teacher's lack of experience with the RVDP system impeded her ability to compare this novel educational technology with her regular math curriculum prior to, and during, the implementation process. Mrs. Hall was required to simultaneously implement two diametrically opposed curricula: the Saxon math scheme and the DM innovation. A brief comparison of Mrs. Hall's regular math scheme (Saxon) and the novel math scheme she implemented (DM) is provided in Table 1:

Table 1. Comparison of Regular and Novel Math Curricula

Saxon Math and Destination Math	
Aligned with standards	
Comprehensive, complete math curricula	
Saxon Math Scheme[a]	**Destination Math**[b]
District mandated	District supported
Adopted district-wide	Adopted early by Mrs. Hall
Basic math curriculum	Optional basic or supplemental curriculum
Prescribed, sequential lesson plans	Optional lesson plans
Prescribed lesson format	Suggested lesson format
Traditional instructional media (text, chalkboard)	Novel instructional media (interactive learning system)
Familiar classroom environment	New computer lab environment
Curriculum control	Optional teacher and, or, student curriculum control

Note. [a]implemented for one 40-minute class period, three times weekly, [b]implemented for one 40-minute class period twice weekly.

The Saxon and DM math curricula can be distinguished in terms of some obvious dualisms: familiar versus unfamiliar; prescribed versus optional; and curriculum-controlled versus teacher and/ or student controlled. These two curricula derive from oppositional epistemologies and exhort contrasting methodologies. The Saxon scheme prescribes routine textbook-driven teacher lecture and student recitation and seatwork. This approach suggests that math knowledge resides in the textbook, although the student may come to share in this knowledge through hard work and honest effort. Conversely, the RVDP interactive learning system does not prescribe an optimal course toward math learning. The teacher and/or the student may choose from the available math resources and thus decide which knowledge is of most worth. This approach suggests that knowledge resides in the interactive learning system (DM curriculum), the realm of real world problems (RVDP news archives), and can be created by the learner (TM open-ended tool-based system).

Saxon's claim to the universality of their math textbook scheme is evident in their call for seamless and programmed implementation of pre-scripted texts–that are suitable for all students and all teachers in all schools. The recommendation by Saxon that the sequence of their lessons should be uninterrupted by alternative texts or variable use, suggests an objective certainty characteristic of *modern texts.* In contrast, the selection of resources provided by the RVDP interactive learning system implies a rejection of the instructional metanarrative (Ozmon & Craver, 1992, p. 380) championed by Saxon. Spring (1991) explained, "Knowledge is not neutral. By presenting the reader with a compendium of information, the modern textbook, in contrast to the postmodern textbook, conveys the impression that scholars agree on a particular body of knowledge" (p. 262). The assortment of math activities made available by RVDP (news articles, open-ended learning tools, and the scenario-based math curriculum, DM, in addition to interdisciplinary resources on the RVDP web-site), represent varied design styles and dynamic representations of knowledge that support diverse instructional uses. The RVDP resources afford multiple representations of content and creation of content by students and teachers. By focusing on this diversity (of activities and implementation options) the RVDP learning system can be described as a *postmodern text.*

To implement DM successfully, the teacher in this research is expected to faithfully use the Saxon regime on Mondays, Tuesdays, and Fridays, and to believe in the DM learning system on Wednesdays and Thursdays. Prior to and during the implementation of the RVDP system, this teacher remained unaware of the schism between the pedagogical contexts for the two curricula she would simultaneously implement. This research suggests that understanding the pedagogical context for any curricular innovation - how it matches with existing curricula, and how it fits with the repertoire of a teacher's current instructional strategies - may be one key to advancing the implementation of novel technologies by individual teachers.

Management Controls on Instruction

Both the Saxon and RVDP math resources had been adopted by the Westridge School District administration to improve eighth grade students' scores on the PSSA math test. Touted as a veritable standards machine by teachers and administrators at Westridge, the Saxon math scheme prepares students to meet the NCTM standards, the National Standardized Tests (SAT 9, ITBS, Terra Nova), and the State standards (including the Pennsylvania Academic Standards for Mathematics [PASM]) by prescribing sequenced, self-contained math lessons organized as inclusive text-based math curricula. Mrs. Hall explained that teaching with Saxon, had become synonymous with teaching to the test. To accomplish both successfully, Mrs. Hall's instructional practices had been reduced to a set of routine, mechanistic, programmed steps:

> The program is scripted so teachers know exactly what to say and how to say it...The difficult work of lesson planning is already done for teachers. The highly structured approach of the Saxon programs makes them very teacher-friendly... substitute teachers can step in and continue the flow of lessons without interruption. Some teachers have even expressed guilt about not having to do as much since they began to use Saxon. (Saxon, 2001, para. 3 and para. 4)

Successful implementation of the Saxon curriculum hinged on Mrs. Hall's ability to execute standards-based curricula by following programmed lists of instructions prescribed by the Saxon publishers. In implementing the Saxon regime, the essence of Mrs. Hall's role as a teacher had been called into question. Ohanian (1999) explained, "Being a teacher means being able to draw your own map – instead of relying on mass-produced tourist guides. Being a teacher means understanding that the best map you draw still is not the territory" (p.151). Years spent using the Saxon regime with her eighth grade math classes had deprived Mrs. Hall of many of the routine decisions one would expect a teacher to make within the course of planning for, and teaching, students. The pedagogical and curricular contexts for Mrs. Hall's math teaching were shaped by controls existing beyond her classroom. At the conclusion of this research, when asked how she might feel about continuing to use DM more frequently with her students in the Fall 2001 semester, Mrs. Hall explained that this decision would necessitate a *restructuring of thinking about curriculum*, one which must take place in the minds of those beyond the walls of her classroom:

> That would concern me, unless we could devise a study group of students, where no one's going to be concerned how much material we covered because since we are addressing standards, and that [DM] does that, supposedly that would be ok. I think as well as teachers having a different attitude about it, school administrators and school boards would take a different perspective on things, I think from like top to bottom, the whole way down too.

While Sarason (1990) has claimed that the structure of students' learning is a derivative of the power of the teacher,"The teacher has the power to alter, even radically, how learning is structured" (p. 89), this research also indicates that the structure of a teacher's teaching may be a derivative of the power of external controls on instruction including the power of the school administration and the political forces shaping educational policy (evident in the imposition of national and state-mandated curricula and testing). These findings show that such management controls on instruction may significantly limit the extent to which a teacher can alter his/her instructional routines during the implementation of a novel educational technology.

Students' Implementation Experiences

Despite these competing contexts for control of Mrs. Hall's classroom instruction, the eighth grade students experienced a level of control over their own learning in the DM class that they had not experienced with Saxon. The educational technology innovation afforded opportunities for students to make instructional decisions regarding the content (what) and delivery (how) of math concepts presented in their DM class.

Students spoke positively about the level of instructional control afforded to them vis-à-vis math activities, the representation of math content and the social context for these activities (the opportunity to interact with their peers) in the DM math class. Each of these student experiences is explored in turn.

Activity Choices

Students who completed their DM tests and prescribed assignments could choose math activities from a suite of DM tutorials (providing repetition of the problem explanation, partial or complete explanation of the problem, and additional practice problems), workouts (sets of complex problems), or progress feedback and reports. Students frequently contrasted the variety and choice of math activities in DM with the limited set of questions in their regular math textbook: "With DM the choices are more fun and there's more of them than over here [regular math class]." Students enjoyed having opportunities to become informed and make choices about their math learning with DM: "Well instead of just, like, being told what to do, you get to think about what you're gonna do. Like you can choose what you wanna do." One student explained that the activity choices in DM enabled him to control what and how he learned math: "You can go with what you want to do and what you think you're capable of learning. I like that you can go at your own pace...You're not held back by other people." My observations confirm students' reports that when using DM, students made instructional choices that supported their own math learning.

For example, as students gained in their understanding of the DM activity system, they used the activity options within DM tests, tutorials, and workouts to increase their individual access to detailed explanations of math problems. Although students were not instructed by their teacher to use the DM *test feedback*, *test report*, and *progress report* activity options, they discovered and employed these tools to review, reflect upon, and regulate their own math learning with DM. Students who scored their DM math test used instantaneous test feedback to compare their own answers to test questions with the correct DM responses provided. The correct-answer feedback provided in DM enabled students to identify the source of their errors by reviewing and reinterpreting both the test question and their own problem solving strategies. As one student explained:

> ...you just say, "Score test!" and then it tells you what you got, and you can go back, and see what the answer should have been and stuff. That kind of makes ya try and figure it out, like, why you didn't get the right answer. It shows you the right answer. So you know how to do it.

The following example represents one student's verbal response to test feedback provided on the first part of her test on integers:

> Oh, why did I do that? Oh! I don't know why I did that! This one was easy, from least to greatest. What did I put? [Locating her own response] What the heck! I put them from greatest to least! For [number] 38 [Pause] Oh, I didn't divide! I never found the average. I was supposed to divide by 10! And I bet that's what happened in the last one as well! Now this one is six, negative six. This is positive, this is negative. So how is it equal? [pause] Oh I didn't times it when I got the number! [Pause] I really need to read the questions!

Students used DM test feedback information in this way to interpret, analyze, and improve their own math performance. Clariana (1990) found that students who received correct answers after one missed attempt outperformed students who were required to repeatedly answer questions until reaching the correct answer. Clariana noted that students who received correct answers after one missed attempt used the immediate feedback they received to clarify misunderstandings and used this information to solve successive problems. In the present study, students used immediate test feedback to begin to understand and affect positive changes in their own learning.

Students who completed and scored a teacher-assigned DM test also received a DM test report which provided information regarding the number of correct, incorrect, and attempted problems, the students' percentage score, and the student's performance on individual learning objectives assessed within the test. Students learned to use the progress report data provided (e.g., percentage of problems correct for each activity, amount of time spent on each activity, and date the activity was completed) to identify gaps in their progress, plan make-up work and navigate the activity options within DM – activities performed by the classroom teacher in the Saxon math class. Students frequently used these accessible and transparent reports of their DM work to appraise their own progress with the learning system.

In this study, students' discovery and use of feedback and report tools to manage their own math learning in the DM class suggests that learners can develop the skill and will (McCombs & Marzano, 1990) to direct their own learning given educational technologies or similar curricular innovations which provide detailed, accessible, and instantaneous feedback to students.

Multiple Representations of Math Concepts

Students also contrasted the multiple and dynamic methods for representation of concepts (audio, visual-graphics, visual-text), in the DM scenario-based math problems, with the static problem sets assigned in their regular math textbook. "The workbook pages are just black and white. It's hard to concentrate in the math class. DM is colorful, and it's more fun. It has cool graphics and pictures and things. You can just listen to the math on there." Students frequently noted the benefits of the multiple pathways to learning (speech, graphics, text) provided in each DM tutorial and workout explanation. They suggested that these three modes for representation of problems supported their interest and engagement in math during their completion of DM problem tasks.

Referring to the audio presentation of math concepts in DM, one student insisted, "It makes it [math] more interesting. And the voices, they say it in a fun way, not like in a serious way, or like a baby way." A peer added, "You understand things way better when you're hearing somebody say it than when you're just reading!" Students noted that the visual representation of math concepts in DM also increased their interest in the DM math activity: "If you have something that you see there that catches your eye, you actually want to do it [math activity]." Students liked the use of animated graphics to support scenario-problems in DM and claimed that these graphic representations of math content supported their understanding of underlying math concepts:

> They give you a lot of pictures and stuff that help. The one sheep thing, like when he was cutting the wool off the sheep to make the things, they had the little sheep in the little circle. Then they colored the circle that had the cut sheep, and they showed you the fractions for how many cut sheep there were to the whole bunch. So, that's a picture that I found helpful to use. Besides trying to figure it out in your head, you have it right there on the computer screen. You can just count it, one by one.

Students noted that in addition to the audio and visual representation of math concepts provided in tutorials and workouts, the step-by step text based explanations of math concepts in DM also supported their engagement in the math activity. One student explained, "They write out the problem for ya in steps. So it's easy to follow."

Students suggested that these three formats (speech, graphics, text) for representation of math concepts in DM motivated them to attempt math problems and sustained their interest in completing difficult word problems:

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> I find it hard to do the story problems. I think I got a lot better at 'em in the lab... Because before when I'd do 'em out of the book, I just [pause] I can do 'em, I just keep, well, I have to read that little paragraph thing there and I always get lost.

In their research comparing the performance of sixth grade students using single-representation (SR) and multiple-representation (MR) versions of a computer-based multimedia program for addition and subtraction of signed numbers, Moreno and Mayer (1999) also found that that the benefits of using MRs with students were strongest on difficult problems. Students in the present study claimed that the multiple formats (audio, visual-graphics, visual-text) for representation of math concepts in DM supported their engagement with difficult math problems by allowing students to choose *how* they wanted to engage with the math problem.

Given these three formats for representation of math concepts in DM, *control* over the instructional event (the math activity) remained a critical factor motivating students' interest in math when using the interactive learning system to complete math problems. One student explained, "You can decide if you want to listen to the problem, or look at it... so you can't get lost. It [choice of representational formats] makes it [math] more interesting." This research implies that multiple pathways to learning which support diverse learning preferences among students may positively affect their interest in subject matter. Hannafin and Sullivan (1995) found that students using either *text-plus-static graphics* or *text-plus-animated graphics* methods for presentation of math topics expressed a more positive attitude toward math than those who viewed the text-only version. In this study, the flexibility of the educational technology in facilitating multiple representations of information enabled students to learn in ways that supported their own pedagogical preferences. Consequently, students found math more interesting when learning with the DM interactive learning system which presented math problems through more than one modality than when using the math text in their regular eighth-grade math class.

Opportunities for Peer Discussion

In the regular math class using the Saxon scheme, students would quietly complete their practice set following the teacher's correction of homework and presentation of the new increment. The teacher neither provided guidelines regarding whether or not students could interact with one another during the DM math class in the computer lab nor organized formal groups or pairs of collaborators. Students spontaneously devised strategies to extend their experience with DM beyond their individual interactions with the interactive learning system to their peers in the math class. For example, many students made exhaustive efforts to synchronize their use of DM tutorials, workouts, and tests with those students seated on either side of them. Students who coordinated their pacing of DM activities in this way consistently demonstrated high levels of interest and enjoyment in the math activity which often proceeded in game-like manner with frequent choruses: "Ready, Set, Go!" "One, two three!" "Marks, set, go!" Students in Mrs. Hall's classes enjoyed learning math with their peers. Many students indicated that the quality of the math experience improved significantly when they had opportunities to work with one another, and make instructional decisions. One student explained:

> It's a different environment thing. You know you're just sitting around doing things, and you find out something new and neat that you just got to show someone, you know, like the people around you. Or if you're getting frustrated with something, the other people are there to like, talk to you about it.

Students rarely sought assistance with DM math problems from their teacher, relying instead on their peers for math conversation and argumentation. Students' discussions of math while using DM progressed through a sequence of stages that included advice seeking, advice giving, evaluation, comparison, clarification, acceptance or rejection of alternative rationales and defense of math claims or assertions. Table 2 presents examples of student math talk at each of these stages:

Table 2. Components of Students' Math-Talk when using DM[a]

Activity	Examples
Request help	"Which one do I click on, here?" (seek advice) "Oh man! What's this about, anyway? (seek help interpreting) "What's an absolute value, again?" (seek definition)
Provide assistance or advice	"Click that one, man!" (provide answer without justification) "Because that's relationship." (provide partial explanation) "Because it's the difference from Jack's home to the school. Do you see that there?" (provide explanation) "Because it's five over two." (provide example of math concept)
Evaluate or compare options	"That looks wrong." (assess) "This one is better." (compare) "Yeah, I had that one figured out, too." (compare, contrast)
Seek clarification	"How do you know it's that one?" (seek justification) "You did what, again?" (seek reiteration of suggestion) "So why did you do that, there?" (seek justification)
Accept option	"That's true." (agree) "Cool!" (accept without indicating motive) "Yeah! That's what I was thinkin' – divide and then simplify. I got that too!" (accept as confirmation)
Reject option	"No it's not! That's a proper fraction there, JM!" (contradict) "No. Eight's the denominator here." (explain) "See, smartie! I told you it was this one, not a whole number!" (self-applaud)
Defend choice	"Oh, no it ain't! That's the opposite of an improper fraction, there, GS!" (reject, justify) "It has to be this one – I know those are all wrong!" (justify by elimination) "If you add them up you'll get four sixths, and that has to be two thirds in lowest terms." (recall mathematical proof)

Note. [a]Excerpted text from students' classroom conversations

The informal nature of students' math-talk (frequently punctuated with vociferous argumentation, lavish expression, and theatrical gesture) during their use of DM belied the depth of students' discussion of math concepts. Through the production of argument and counter argument, students frequently attempted to persuade their peers that certain choices or decisions were preferable to concurrent choices or decisions in resolving DM math problems. Students demanded support and justification for mathematical assertions and claims presented by their peers; these demands were met using mathematical data, facts, and evidence.

This research supports the claim that novel educational technologies can trigger a restructuring of classroom experience: extending and elaborating the possibilities for student interaction (Kerr, 1996). In this study, the interactive learning system provided a powerful motivational forum for students' discussion of math concepts and ideas. Students used the motivational instructional tools afforded by the DM to continue their math experiences through conversation and argumentation with one another. Providing opportunities for students to extend and elaborate their experiences with motivational educational technologies may be a key factor determining the extent to which these technologies impact students' learning experiences.

Increased Interest and Engagement in Math

For the three reasons discussed (activity choices, multiple representations of math content, and opportunities for peer collaboration) students claimed that using DM increased their interest in and their engagement in and productivity with math: "The choices are just more fun, and there's more of them, and it's more interesting to see an' hear the math. You're just busy all the time." One student explained, "With DM you actually want to do the math, then. And it means you actually want to work harder and, like, get it done, and see how much you can cover and stuff." Another student contrasted his poor work ethic in the regular math class with his sense of efficacy when learning with DM: "Well here I could actually get my work done. I could actually do my work in here. Over there I would do nothin' cause I'm lazy and it's boring. Here it's a lot better... DM helps. It gets you to like it a little more, so you actually get to do stuff. You want to do work: you don't just sit there".

My observations of students' math discussions and activities with DM supported their self-reports of increased engagement with math in the DM class. During their first visits to the computer lab to use DM, I noted that students accessed the system with little delay, engaged in math-talk with one another, completed prescribed assignments, and frequently remained in the computer lab beyond the five-minute bell which signaled the end of math work in the regular math class. To document students' level of engagement with math when using DM, I routinely described the activities of a random sample of approximately one third of the students in each of the eighth grade math classes approximately ten minutes into each class session with DM, occasionally repeating the activity with a new sample of students ten minutes before the end of each session. Table 3 summarizes the activities demonstrated by students while using DM in the computer lab, classified as time-on-task and time-off-task, based on 21 recorded observations (one for each student sample) taken in 15 DM math classes:

Table 3. Description of Time-on-Task Categories

Time-on-Task	**Time-off-Task**
Student engaged in math talk: Student discusses math with peer or teacher Student reads or thinks-aloud math	Student talk is not about math: Student asks peer for gum or candy
Student engaged in math activity: Student performs calculations using calculator or paper Student proceeds from one screen to another without visible distraction	Student activity is not about math: Student reads book of English poetry
	Student is disengaged from math activity: Student randomly clicks buttons on screen without obvious purpose or progression Student closes DM program and logs off computer before the 5 minute bell

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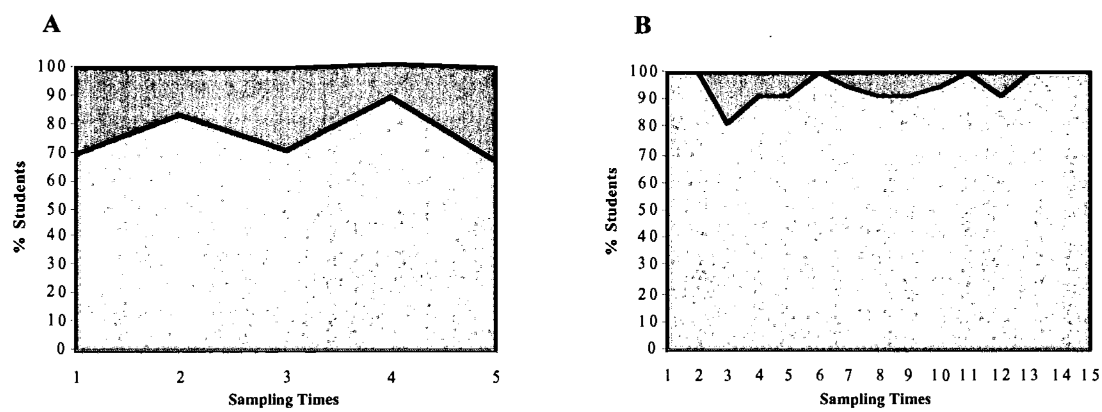
	<u>Student faults hardware for time-off-task:</u>
	Student restarts computer
	Student changes monitor settings
	Student handles power chords

To explore further students' claims of high levels of engagement with math in the DM class, I used the categories represented in Table 2 to classify the behavior of each student within each observation sample as either on-task or off-task. Figure 2 graphically represents this time-on-task data, which was taken for students in both their regular math class, during the four-weeks prior to the implementation of DM (Figure 2 A), and in the DM math class during the ten-week implementation process (Figure 2 B):

<u>Figure 2</u>. Students' Time-on-Task in the Math Class



In contrast with Figure 2 A which represents descriptions of students' time-on-task in the regular math class, Figure 2 B shows that an average of 95% of students were found to be on-task with math, when using DM. From the first until the final log, there is very little variation in students' time spent on-task, while using DM. Students' engagement with math in the DM class, defined operationally here as time-on-task, began and remained high throughout this ten-week implementation of the interactive learning system for math. This analysis supports students' claims that they were more interested in math, and more engaged in math activities when using DM, compared with their regular math class, using the Saxon math scheme.

Conclusions and Recommendations

Existing research advocates the use of educational technologies in classrooms to increase students' interest in specific subject matter (Webster, 1990; Yusuf, 1995). The present study supports this claim and proposes that the level of learner control afforded to students by an educational technology is positively related to students' level of interest in and engagement with the subject matter. Researcher observations of students' use of the interactive learning system in their math class, combined with individual and focus group interviews with students, suggest that the activity choices, multiple representation formats for learning, and opportunities for peer discussion of math concepts that students experienced when they used DM to learn math increased students' interest in math and resulted in high levels of engagement with math. Students experienced high levels of control over the instructional enterprise when using the interactive learning system.

While learner control has generally been used to refer to the delegation of instructional decisions to learners regarding the sequence and pacing of instructional activities and the identification of learning needs (Johnson and

Johnson, 1996), this research suggests that learners' decisions regarding the social context for their learning are also critical to our understanding of how learner control evolves during the classroom implementation of educational technologies. Further exploration of students' math talk while using educational technologies for classroom learning would inform our understanding of how students support one another in developing learner-control strategies during the initial implementation of educational technologies in their classes. This research would enable us to identify strategies that students adopt or co-create to control their own learning using linear and open-ended learning systems in classrooms.

This research suggests that in classroom environments which afford opportunities for students to display what they know and what they can do when using motivational educational technologies, students' classroom conversations, or math-talk may provide compelling evidence of their understanding of math concepts. Implications for classroom practice include providing opportunities for students to engage in sense-making practices with their peers as they work to understand mathematical concepts. As educators, we are called to redress our unfamiliarity with children's ways with words (Heath 1983) - their ways of organizing their experience and expressing meaning - and examine how technology enhanced learning environments may provide a catalyst for exploring evidence of understanding in students' classroom conversations.

This study shows that by increasing students' opportunities to exert their own instructional preferences in learning required course content, educational technologies may positively influence students' interest in and engagement with subject matter. While students may readily adopt new instructional roles in technology enhanced environments, the present research suggests that instructional change may be a much slower process for teachers. The absence/existence of a robust professional development support strand for technology-implementing teachers may significantly influence the success of their implementation efforts. This research calls for sustained professional development to facilitate a teacher's exploration of the alignment between the instructional affordances of the educational technology innovation, the teacher's current instructional strategies, and management controls on the teacher's classroom instruction. Given the teacher's decision to reduce her use of the educational technology to one day per week in light of the tangible benefits for her students, this research challenges us to develop adequate supports for technology-implementing teachers, and to further explore the evolution of learner control in technology-enhanced learning environments by re-examining the role of the learner in instructional contexts.

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