Functioning in the Wireless Classroom

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Abstract

Code It! fosters mathematics learning environments where pre-algebra students use handheld technologies to explore and learn about functions. The resources developed—server-based and handheld software and paper-based student and teacher texts—were packaged as a 20-session unit on code making and breaking and designed to boost students' understanding of functions and their facility with the multiple representations of tables, graphs and symbols. We field tested the wireless system with two teachers and 120 students during summer school, and conducted studies on the features and function of the technology as a learning and teaching resource. We report on project development and research, focusing on lessons learned about the strengths and difficulties of wireless, handheld technology in the mathematic classroom.

1. Need

This is a particularly important time to develop and research technologies for math learning. Across the US, there is a push to raise lukewarm achievement results on standardized tests and international comparisons. The *Code It!* materials—technology and real world based—were designed to address this challenge, capitalizing on developing technology for stimulating high performance while providing a satisfying, successful math learning experience.

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Technology should be providing tools to support the activities of mathematics classrooms, yet many problems have accompanied classroom computer use: prohibitive cost, use models that do not mesh with classroom structure, and a learning curve for teachers that has been too high for too little gain. Even when researchers developed compelling exemplars [1,2], changes in organizational, social, and pedagogical practices with computers produced high hurdles [3,4]. The combination of increased access, increasing teacher knowledge, decreasing technology costs, and new portable devices is creating a synergy and new possibilities for mitigating problems.

Early studies of handheld technology use are modest yet suggestive of how they might best be applied [5, 6, 7, 8, 9, 10]. These are promising trends, and to tap the potential, we developed an application for enhancing students' math learning by providing representations that are easily manipulated, and by creating a context for learning formalisms [11,12]. The project enabled us to address three research areas:

1.1. Enhanced mathematics learning.

Do the materials and wireless tools enhance student learning of algebra concepts and skills? What progress do students make in reasoning with representations of patterns and functions? In communicating mathematically? Do we see increases in productivity with this approach? Is engagement with math high? Do the materials boost student achievement?

1.2. Enhanced teaching.

Through partnerships with teachers we learn about conditions for success and needs for further development. Will teachers benefit from unit teaching tools and access to server-based group and individual data? What are the critical issues in teacher learning and appropriation of this technology?

The results stand to influence the design of a generation of math tools by indicating ways that server-based communication, data tracking and storage capabilities can enhance the teacher's role.

1.3. Productive tool use.

How well do wireless handhelds or desktop computers work as a tools for math learning? What are the resources and obstacles to use of the handhelds, network infrastructure, and collaborative activity structures for learning mathematics?

2. Our Response and Approach

The project was structured around three strands of activity: materials development, work with teachers, and field test research. Each is discussed in turn.

2.1 Materials development.

We created a technology-integrated 20-session curriculum unit on linear and quadratic functions, with a code making and breaking theme. The unit places algebra learning in a real-world context—making and breaking secret codes [13]. Students can challenge others to break their codes to determine message content. Students must examine properties of functions in general, learn to distinguish among “families” of functions (e.g., linear vs. quadratic) as well as learn properties of each family (effects of changes in constants to graph, for example). Connections among symbols, tables and graphs are emphasized.

Code It! was inspired by a curriculum unit, *Codes, Inc.*, developed by the Middle-school Mathematics through Applications Project (MMAP), which won recognitions as a promising middle school mathematics curriculum by two US Department of Education expert panels. Evaluation showed teachers found the MMAP codes unit helpful for transitioning to technology use and reform-based curriculum [14]. Teachers saw real values for the unit to aid learners' development of needed algebra skills and concepts.

2.1.1 The change from desktop to WILD. The advantages of the wireless version of the software over the desktop version seemed obvious. With hand-helds, students can create and exchange codes easily, and records of their work and solutions can be captured on the server. We hoped the technology could leverage increased interactions with mathematics and embedded assessment activities. In the desktop software developed by MMAP, exchanging the codes

was based on cumbersome e-mail, now supplanted by wireless communications.

Code It! software is built around an in-room wireless network which allows students to work on codes together and to share codes between groups. Each PDA is connected wirelessly to a teacher's station in the room. The station runs administrative software that allows the teacher to control and monitor groups in a variety of ways. The teacher can monitor which students are logged into the server, place students into groups, create and distribute practice problems, and open observer windows that display a group's current state. In addition, the server logs each group's activity, allowing for a teacher or researcher to reconstruct the precise ways that students were using the software and solving problems. The server also is a repository for text and codes created by the teacher and students, providing a way to share codes among groups and to distribute practice problems.

Image 1: Graphical screen view of a code solution.

Each PDA runs *Code It!* software that allows students to create plaintext, to make and break codes, and to upload and download text and codes from the server. When making or breaking codes, the student's screen displays the encoding function (or current guess) and the graphs and tables that represent the function and the coded text.¹ These representations

¹ For this implementation of the software, these various representations are displayed on a single long, scrolling screen for bringing the representations into view. While it proved less than ideal, our focus was on ensuring that the software was robust, and the design generally functioned well. This interface issue will be corrected in future versions.

include a graph of the function, a function table, and word and letter frequency tables, selected in order to foster particular kinds of learning, rather than to create an ideal coding tool. All of the PDAs within any given group are bound together via the server. A change made by one student propagates to the other students in his or her group, so the PDAs within a group always display the same function and text. Students in a group could each view a different representation of the function under consideration. The goal is to foster communication among group members and increase the diversity of information available for the coding or decoding task. When a group successfully breaks a code, it instantly receives a congratulations message.

2.1.2. Instrumentation. Beyond its use for synchronizing the students in collaborative groups, the server stores all messages being worked on by different groups. It also provides administrative functions. Teachers may define groups and assign students to groups. It allows both teacher and students to write and edit plain text messages with a normal keyboard, not just the restricted keyboard of the PDA. The server also logs communications to and from the PDAs that later recreate the PDA display for any group at any particular time.

2.2. Work with teachers.

The professional development component turned out to be as important as the materials and software in ensuring that students get a well structured, engaging and deep mathematical learning experience. Teachers “choreograph” the performances of classroom tasks and activities to enable students to engage mathematical ideas, language, and practices. Teachers are also faced with supplementing their adopted materials to meet students’ needs, adjusting to increase coverage, and to emphasize particular kinds of thinking, problem solving, and communication.

We know that teachers must do a great deal of work to arrange productive participation structures in their classrooms, and we need to learn about how they can incorporate wireless technology. For their part, teachers need time to learn and develop both teaching sensitivities and practices with technology. Their professional development is crucial.

Professional development included three days of training and planning with the teacher partners as well as just-in-time, in-class support. The workshop included:

- Time for being introduced to the technology including PDA use and the teacher station.
- Early access to review of the curriculum unit, and discussion and revision of each activity.

- Practical planning advice and session-by-session planning time for implementing technology, including management of technology issues such as battery life, the class activity schedule and student roles.
- Just-in-time daily consultations on math and technology while implementing the unit.

Our time with teachers was extensive, but crucial for helping us to uncover the strategies they used to orchestrate the use of handhelds, and identify the obstacles and affordances they inherited.

Image 2: Function table view of a code solution.

Plain Text:			
I SIT BESIDE THE FIRE AND THINK OF PEOPLE LONG AGO, AND PEOPLE WHO WILL SEE A WORLD THAT I SHALL NEVER KNOW.			
Function Table:			
X	Y	X	Y
1	3	14	588
2	12	15	675
3	27	16	768
4	48	17	867
5	75	18	972
6	108	19	1,083
7	147	20	1,200
8	192	21	1,323
9	243	22	1,452
10	300	23	1,587
11	363	24	1,728
12	432	25	1,875
13	507	26	2,028

2.3. Project questions and methods.

Our research goal was to test the usefulness of the materials and to generate knowledge about the ways in which they were effective. We collected several data streams, including observational data, videotapes of teachers and the four-member student groups in the classrooms, problem-solving and informational interviews with student dyads, and pre- and post-tests of mathematics knowledge. These methods, of observing and videotaping classroom field tests of materials and feeding back results into the design, enabled our development team to define areas for revision based on the use of the materials under real classroom conditions [15,16,17]. The cycle of development and field test supported our learning about how teachers and students received the materials and how best to iteratively improve the design for achieving the teaching and learning goals.

It is part of our method to track topics and issues as they emerge in field tests and teacher workshops, and

to then interview, videotape, and interrogate. We look first for obvious patterns of structure such as who is involved in planning and activities, how the space is set up and how and when people move around in it, what the flow of activities is from start to finish, what materials and resources are used, how and when teachers and students talk, what they talk about. After searching for some of these basic structures, or because of “noticeable” events, other areas for analysis emerge. These methods are complimented by the use of problem-solving tasks and pre-and post-tests with students and interviews and surveys of teachers.

The research process is characterized by an inter-relationship among field-testing, development, and evaluation. For instance, prospective materials emerge from focus groups, get written, and get put into the field test, after which they are evaluated and revised.

We partnered with the Stanford Teacher Education Program and the Santa Clara, CA Schools to use *Code It!* with all of the district middle school students in their five week summer school program. Each teacher had 60 students split between two consecutive 100 minute class sessions: one teacher used handheld iPaq computers (PDAs); the other used Compaq Tablet PCs. This analysis focuses on the PDA classrooms.

Image 3: Student group working on *Code It!*

We pre- and post-tested students with mathematics vocabulary items, short answer problems based on unit concepts and representations, and released pre-algebra and algebra items from the California High School Exit Exam. We collected video on 120 hours of classroom time, using two cameras in the PDA classroom each day. This enabled us to “follow” the activities and progress of four groups of students in the classes. We also interviewed twelve pairs of students (N=24) from those groups. For students in our focus groups, we have pre- and post-tests, an interview where they were asked to problem solve and break a

code, and a video record of their activities and progress through the unit. In addition, the server provided a record of process steps for each group.

3. Lessons Learned

Analysis is preliminary, yet we have some encouraging results on how our learning technology design functioned, and the ways in which teaching and learning were affected. Whereas we have outlined the project with three categories of interest, our results reinforce the synergistic nature and interactions of the technology, the teaching and the learning. We do not report on them as if they were mutually exclusive because we observed them in the flow of classroom activities where their affordances and constraints melded into resulting situations and events. So we present here observations where the constellation came together in mutually reinforcing ways or in negative ways. We are able to offer some next steps that we have identified to improve the *Code It!* experience and some of those steps point to specifics of students’ math learning, how teacher can make the most optimal use of the materials, and how the design of the *Code It!* technology itself might change.

3.1. Students and math.

Two aspects of student work dominated our attention. The first was meeting our goals of getting students to interact with, discuss, and use the mathematics. The second was the establishment of the social arrangements needed to support working with the tools to meet the math engagement goals.

3.1.1. Students’ interaction with mathematics. To date, we have analyzed results of the pre- and post-tests in the PDA class with our targeted student groups and the results were promising (N=45). The mean increase from pre- to post tests was eight percentage points; in four of six focus groups, students made significant gains, in some cases raising their scores by 15-30%. The PDA students showed significant gains on items relating to evaluating exponents and the graphs of functions. On one graphical item, 44% of students answered correctly on the post-test, as compared to only 13% on the pre-test. What is exciting about these trends is that these results were for students in grades 6-8 who were placed in heterogeneous groups regardless of their previous school math course achievement. Many students in the class had done poorly in sixth or seventh grade math, while some students had completed the first year of algebra. The algebra students were encouraged to help

others, and the pre- and post-test results indicate that these interactions may have had an impact.

3.1.2. Focusing on the Curriculum. Keeping the attentions of students on the mathematics took a great deal of social engineering on the part of the teachers and the development team. The team had to mitigate the effects of the widely heterogeneous groups and the constraints that the *Code It!* tool entered into the equation. We treated these as both challenges and opportunities. During the teacher workshop, we discussed these constraints and decided to introduce rotating social roles inside the groups in order to make sure all students had a chance to work with all aspects, tools and representations during the problem solving process. Once the students started learning how to code and decode using the PDAs, an anarchistic atmosphere emerged in the classroom. The teacher mentioned the group roles, yet students forged ahead without obvious attention to them.

We saw “stylus wars” break out among students who were vying for control of their group’s PDAs and communication with the server. Heated discussions arose and the chaos and discontent led us to work with the teaching staff to enforce roles that would foster group collaboration, rather than competition. Linking the process roles of (1) recorder, (2) presenter, (3) publisher and (4) equipment manager to the different code representations in the software, and rotating these roles avoided much of the inter-group conflict, but also contributed to more engagement on the part of more students in code analysis and breaking activities. In addition to group roles, the teacher and summer interns instituted and enforced a rule stating that “all students in a group must be able to explain the strategies and routes to solutions in order to receive credit.” That meant that if the more skilled and experienced students in the group solved a code before others, the entire group had to review the steps taken, the strategies used, the solution, and be able to demonstrate it using a PDA. This increased team cooperation, and resulted in a practice of questions and explanations across group members. Teams spent time working together to make sure they could each explain their problem solving if asked informally by a teacher or if asked to present to the entire class.

Due to the social engagement rules, we saw more consistency of performances on the part of the students over time. Early on we observed a full range of performances, from students engaging in some extremely rich and iterative collaborative problem-solving processes, to students relying on simple guessing strategies, to students avoiding work altogether. After instituting the social rules for “student roles” and the “explanation rule for credit,”

new patterns emerged, and we observed multiple instances of the students who took problem-solving approaches talking with those who usually guessed or seemed uninvolved. The social engineering improved group relations and engaged students more deeply with the software and the mathematics.

Image 4: Teacher’s view (server screen).

3.2. Teachers.

Findings about teachers and their work fall into three categories: (1) teacher training and teacher knowledge; (2) teachers’ appropriation of the technology; and, (3) teachers’ “workarounds” for the technology’s shortcomings.

3.2.1. Teacher training and knowledge. Even though teachers participated in three days of teacher professional development that included explorations of the unit and the technology and individually practiced using the teacher station and the PDAs, the situations that developed when twenty-five to thirty students were using the system in class outstripped their novice knowledge. While the teachers were clear on the basic operations of the PDAs, they were caught by surprise concerning student engagement and in the ways the software could be used to pose or solve particular coding problems. As the days of the field test went by all three of these teacher practice areas improved. Our continued work with the teachers on a “just in time” basis addressed some of the teachers’ lack of prior experience. During the first two weeks of the unit, the teachers grappled with understanding the potential of the technology to help students problem solve. In one of several meetings between a math educator on our staff and the teachers, the strategies for working to decode were explored. An outcome of the meeting was to have our staff member co-teach one lesson to

demonstrate a systematic way to use *Code It!* to crack more difficult codes. Once this happened there was an increase in student productivity in code breaking. We realize in analyzing this incident that we were unable to have predicted the teacher's need for scaffolding in order to use *Code It!* effectively with the students. Next steps will include more classroom problem simulations for the teachers to work with that can be fashioned from this year's field test. This will help teachers to learn how the tools are best used for problem solving affiliated with the unit.

3.2.2. Teachers appropriated the technology. The teachers actually did a great deal of work to make the technology useful for meeting the curricular goals. *Code It!* presented them with a set of challenges and complexities to manage and, in some instances, overcome. We saw the teachers appropriate the technology into their teaching practices. One teacher found a way to use the blue and white circles that showed the active status of every student in each group on the teacher station screen as a classroom management tool, keeping track even from across the room of which students were on-line and which groups were most active. This enabled him to troubleshoot for students who were having log-on issues as well as to visit groups that were lagging behind in the activity. The same teacher used the teacher station to develop activities and code breaking problems when he saw the need for more scaffolding between simple and more complex codes. One student teacher in the classroom used the teacher's station to develop problems and lessons. This gave teachers the opportunity to assess students' work and needs, to create hand-tailored activities and problems, and to organize them so they were available to the students. Both teachers used projection equipment so they and students could discuss with visual aids the various strategies for code breaking as well as demonstrate the use of the different *Code It!* tools. This demonstrated how the system was robust in use and how teachers made it compatible with their teaching practices.

3.2.3. Teachers worked around technology shortcomings. Some constraints in the technology caused rifts in the smooth flow of classroom activity and the teachers found themselves compensating when needed. The constraints were many and ranged from overload during whole class log-on, to the lengthy scrolling screen with multiple representations of data, the fact that some of the representations of coded data were more useful to students than others (e.g., as the system could only handle short codes they could not benefit much from word frequency analysis data), to the fact that the system could log only group work.

The teachers created short codes when they provided supplementary activities, shared strategies for working with all of the representations, reminding students of how to find them, and established and enforced a series of roles and expectations about the sharing of code breaking solutions to mitigate the fact that but one PDA in each group could communicate with the server at a time (and return new results in a graph of the function entered, for example) as *Code It!* tracked only group activity.

Together, these findings about teacher work indicate that, although the technology introduced a need for all kinds of management of instructional activities, the teachers demonstrated a steep learning curve and an ability to strategize, plan and respond to student and technological difficulties, and to capitalize on the tools to facilitate math learning.

3.3. Technology design and performance.

Three features of *Code It!* were shown to need reworking during the classroom test: (1) the ways mathematical representations and tools are organized; (2) the choice to base the system on group activities and interaction over individual acts; and, (3) the design and usability of record keeping functions—potentially so promising with wireless technology. Each is discussed in turn with examples to illustrate reconsideration of the design. Our original goal was to produce a first, yet functional and robust version of *Code It!* in a twelve week development period to have it ready for the summer 2003 classroom test. We accepted the short development time line because we were interested in partnering with the teacher education program and the summer school. To us, this was both a service and an experiment. That time line resulted in several design compromises and issues to address in the next iteration.

3.3.1. The organization of mathematical representations. The ways that students came to interact with the multiple tools and representations for understanding and finding code keys revealed side effects of our choices. The first representational issue arose from the choice to employ the lengthy scrolling screen for accessing different representations instead of using a multiple windows approach. While the scroll function was easy for students to learn and use, it gave prominence to the first representation showing on the screen (the graph), with other representations absent from view without scrolling. We worried that giving prominence to the graph would signal a hierarchy to students, and it did. We constructed the curriculum materials and a process for introducing the other tools and representations (a function table, letter

frequency and word frequency tables). The group process and daily rotation of assigned roles that attached students to one of the function representations was a compromise between the constraints of the system and the ways students could best benefit from the representations available. Although the system of each student having a portion of the data displayed for interpretation on his/her PDA encouraged group collaboration, it meant that on any given day a student had the responsibility to relate to only one view of the data. We were able to deduce that the multiple representation capabilities of the software is a strength and real resource for mathematical work and learning. A question that now remains for investigation is how structured or unstructured students' access to those representations should be.

This is significant because we also discovered that representations were unequal in their familiarity and usefulness. The graphical tool was extremely powerful because the data window automatically fits to the values of the coded text. This enabled students to do a kind of curve-fitting that usually got them close to a correct code. Many of the students could determine the presence of an exponent in the code graphically, and often the lead coefficient as well by adjusting the graph. The function table was just as powerful, though far fewer students learned how to use it well (at least partly because of a programming error that we corrected for halfway through the course). The function table was two tools in one, because it had an inverse function table embedded in it. That table was confusing to most students, and even those who had already taken first-year algebra operated with misconceptions. The word frequency table was used even less due to the fact that our coded text passages were short due to the software slowing down with long passages. Students rarely used it, except to guess which numbers might be representing the single-letter words "I" and "a". These differences in representational placement, form and usefulness had consequences—the students assigned to the graph and the function table were able to be most involved.

It is not clear from our field test that our work on representations was completed to satisfaction. We came away from the field test questioning whether the multiple representations provided an appropriate level of scaffolding for the students' understanding. Some groups quickly found simple strategies that led them to crack codes without improving their knowledge of functions. For example, some students consistently and repeatedly used the graph of a function as predictors of the range and domain of the encoding function, methodically changing values in the function until the axis labels came within the range of the letters of the alphabet. Others consistently sought out

single, two, and three- letter words, as well as mappings for the most common letter in the English language ("e") as a path for breaking codes. We have discussed incorporating a prediction capability to the software, which could alert the teacher or team itself when a group is in danger of depending solely on a particular pattern of code breaking.

3.3.2. The choice for group over individual. Our design decision was to bias the function of the system to support groups over individual students. This was a choice we made early on in order to be able to experiment with the capabilities of the teacher station data collection. This decision proved to be extremely constraining in the classroom, and needed many socially engineered workarounds. Students wanted to play and explore when they had PDAs in their hands, but were unable to do so unless it was their assigned role to communicate for their group. They had trouble orienting to these rules, and often competed for control and communication with the server. Many cursors broke out in groups. When the wars were resolved in favor of strict, daily roles, some students became alienated. They were discouraged, and some were bored. This led them to discover other features of the PDAs such as appointment books, animated messages, and games such as Solitaire. Our desire to have the group at work and record all group transactions resulted in some students tuning out when they had a less-than-critical role assigned. Schools also rely on individual accountability, and the system was unable to account for individual problem solving activity. As a workaround, we sought to set up a group for each student, but the system could not handle 30 groups.

3.3.3. Rethinking record keeping functions. When we designed *Code It!* we were pleased to experiment with the kinds of information and data that the server could provide to the teacher. The server did keep track of a great deal of information about group problem solving. Unfortunately, these records were not immediately recoverable by the teachers and more work will have to be completed to develop a useable interface on student work. We discovered that students also needed access to records of their problems and solutions. It became a whole class activity for students from groups to share with the entire class the ways they approached and broke codes. Even though groups kept notebook records of their strategies, students found it difficult to make use of them after the fact.

We plan for the next version of the software to support easy access to records of problem solving by the students. We seek to address the ideal balance between scaffolding for collaboration and individual exploration of the encoded functions, within the *Code*

It! software environment, so as to lessen opportunities for disruptive stylus-wars. Our upcoming iteration will incorporate a flexible grouping mechanism, while maintaining both the appeal of collaboration and software robustness that made this first experience with *Code It!* successful. We are also considering ways to decouple the individual PDAs from the system. This would allow for students to explore and problem-solve individually as well as in groups, as well as provide opportunities for “anytime, anywhere computing”. These home and family connections would capitalize even more on the potential of portable, wireless technology.

4. Conclusion

We had a successful field test of the *Code It!* wireless application under extremely constrained, yet real, classroom conditions. Now that we have an idea of how students and teachers actually put such devices and software to use, we can develop a next version. This will result in a more aesthetically pleasing and useful application that fits the interaction, content, and assessment demands of the mathematics classroom.

5. References

- [1] *Middle-school Mathematics through Application Project Final Report to the NSF* (1998). Menlo Park, CA: Institute for Research on Learning.
 - [2] Roschelle, J., Pea, R., Hoadley, C., Gordin, D., & Means, B. (2001). Changing how and what children learn in school with collaborative cognitive technologies. In M. Shields (Ed.), *The Future of Children* (Special issue on Children and Computer Technology, published by the David and Lucille Packard Foundation, Los Altos, CA), Volume 10, Issue 2, pp. 76-101.
 - [3] Goldman, S. (2001). Technology in the Mathematics Classroom: Guidelines from the Field. *ERIC Update. ERIC Clearinghouse on Information and Technology*, 22 (2). (<http://ericit.org/newsletter/Volume22-2/goldman.shtml>)
 - [4] Means, B., Penuel, W. R., & Padilla, C. (2001). *The Connected School: Technology and Learning in High School*. San Francisco, CA: Jossey Bass.
 - [5] Soloway, E., Grant, W., Tinker, R., Roschelle, J., Mills, M., Resnick, M., Berg, R., & Eisenberg, M. (1999). Science in the palm of their hands. *Communications of the ACM*, 42(8), 21-26.
 - [6] Curtis, M., Luchini, K., Bobrowsky, W., Quintana, C., & Soloway, E. (2002). Handheld Use in K-12: A Descriptive Account. *Proceedings of The First IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'02)*, pp. 22-30). New York: IEEE Press. .
 - [7] Luchini, K., Bobrowsky, W., Curtis, M., Quintana, C., & Soloway, E. (2002). Supporting learning in context: Extending learner-centered design to the development of handheld educational software. In *Proceedings of The First IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'02)*, pp. 107-111). New York: IEEE Press.
 - [8] Vahey, P., & Crawford, V. (2002, September). *Palm Education Pioneers Program: Final Evaluation Report*. Menlo Park, CA: SRI International. (<http://www.palmgrants.sri.com>).
 - [9] Roschelle, J., Patton, C., & Pea, R. (2003). To unlock the learning value of wireless mobile devices, understand coupling. In *Proceedings of The First IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'02)*, pp. 2-7). New York: IEEE Press.
 - [10] Tatar, D., Roschelle, J., Vahey, P., & Penuel, W. R. (in press). Handhelds go to school. *IEEE Computer*.
 - [11] International Technology Education Association (2000). *Standards for Technological Literacy: Content for the Study of Technology*. Reston, VA: ITEA.
 - [12] President's Committee of Advisors on Science and Technology and Panel on Educational Technology (1997, March). *Report to the President on the Use of Technology to Strengthen K-12 Education in the United States*.
 - [13] Singh, S. (2000). *The Code Book: The Science of Secrecy from Ancient Egypt to Quantum Cryptography*. New York: Anchor Books.
 - [14] Lichtenstein, G. Weisglass, J., & Erickson-Alper, K. (1998). *Final Evaluation Report: Middle-school Mathematics through Applications Project*. Denver, CO: Quality Evaluation Design.
 - [15] Brown, A. (1992). Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *Journal of the Learning Sciences*, 2(2). 141-178.
 - [16] Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher*, 32 (1), 9-13.
 - [17] Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32 (1), 5-8.
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