Dynabook: Supporting Teacher Learning about Mathematical Thinking

Jeremy Roschelle, SRI International, Menlo Park CA, Jeremy.Roschelle@sri.com
Charles Patton, SRI International, Menlo Park CA, Charles.Patton@sri.com
Elizabeth Murray. CAST, Wakefield MA, bmurray@cast.org

Abstract: To advance the conference theme of the “future of learning,” we report our investigations of how the change from paper textbooks to digital curriculum resources may change the Learning Sciences, and how, in response the Learning Sciences could grow to make significant advances to digital curriculum resources. We highlight the changing relationship of the “reader” and the “resource” in digital age. We believe something like a “textbook” will continue to be a central focus and source of structure in future learning environments, but that unreflectively carrying forward textbook conventions and assumptions about how “reading” relates to “learning” may not be productive. Building on universal design for learning (UDL) theories and our own “Dynabook” investigations, we sketch a framework for rethinking the nature of digital curriculum resources and highlight how the field of the learning sciences might grow to play a stronger role in the coming tidal wave of “digital first” learning resources.

Introduction
One of the largest, most powerful trends in education today is the transition from paper to digital textbooks (Education Week, 2011). Although some futurists imagine textbook-like resources disappearing, we suggest that there is a stable educational need for curricular resources that (a) structure the long-term learning progression in a course or topic (b) are carefully edited for coherence, etc. and (c) convey authority. Hence, something like the textbook will continue. But if something too much like the textbook continues, what a missed opportunity!

As much as textbooks provide a central resources for organizing and structuring what teachers do, they have an insufficient “theory of action” with regard to teaching and learning (Ball & Cohen, 1996). Students buy or are given textbooks on the theory that student use of the textbook will advance learning. The most common use model is that a teacher reviews key definitions and solution methods from the text with students and then presents the students with selected problems from the book to practice on. However, this use model for a book does not lead to either effective teaching or meaningful student learning -- and thus “supporting” use in a digital medium may be an advance.

An alternative to digitally-enhancing the existing textbook model is to start from learning sciences insights about how to prepare teachers, and to consider how those insights could be more systematically supported in a digital medium. Perhaps the single most valuable lesson from the learning sciences is that when teachers learn how to empathize with, make sense of, and work with student thinking, they often are able to enact better instructional strategies for their students. For example, this principle has very successfully been applied in Cognitively Guided Instruction (Carpenter & Fennema, 1996). Based on this principle, we have been exploring an alternative “theory of action.” We propose that a “dynabook” for use in teacher education can engage preservice teachers in considering how students think, examining their own mathematical thinking as a teacher, and framing more sophisticated pedagogical approaches towards helping their students.

In this paper, we present some mid-term reflections on our progress in crafting the “Proportionality Dynabook”, testing it in teacher preparation courses in two universities, and reflecting on where we need to go next to fully realize the potential of the new digital medium for textbook-like resources. The main contributions of this paper are to (a) share some our early failures (b) describe a compelling purpose for a dynabook for teacher education (c) introduce a potential new metaphor for the endeavor and (d) elaborate some of the research questions that are still outstanding at this early stage of inquiry.

Background: The Dynabook Project and Team
The Dynabook Project has been a design research effort, aimed at crafting a new resource for use in teacher education based on the emerging potential for digital books. A quick sense of the project can be expressed by describing the partners. SRI International brought experience in creating effective digital materials for learning mathematics using dynamic graphical representations (Roschelle et al, 2010) as well as experience using a co-design methodology to build new things that reflect the input of multiple stakeholders (Penuel et al, 2007). A
nonprofit organization with a long history of work on reading and in special education, CAST, provided an engineering framework for creating interesting digital texts, based on its own work in Universal Design for Learning (Rose & Meyer, 2002; Rose, Meyer, & Hitchcock, 2005). Two campuses of the California State University system each brought innovative professors who were working to introduce prospective teachers to better ways to teach mathematics. The professors at San Francisco State University were more focused on special education teachers, whereas those at San Diego State were more focused on general mathematics education teachers. In addition to Universal Design for Learning (UDL), the TPACK framework has been influential in the project as a way to relate mathematical content, pedagogy and use of technology in learning (AACTE Committee on Innovation and Technology, 2008). Inverness Research, in the role of evaluator, has been acting as a critical friend to the project, seeking to engage the whole team in working on the most important and provocative questions in this area of work. As a whole, the project team has developed several iterations of a web-based dynabook, focused on the mathematics of proportionality, and tested the use of the dynabook in teaching experiments at both universities. Figure 1 shows a current version of the Proportionality Dynabook.

One bit of terminology that has been useful throughout the project is to use the term “candidates” for students who use the dynabook, because these students are studying to be teachers, and thus both the word “student” and “teacher” are confusing. “Teacher educators” are the university professors who teach the candidates, and “students” are the middle school children who the candidates will eventually teach.

We organize this paper by telling the story of the first and second versions of the dynabook we created and anticipating a possible third version, which has not yet been fully realized. Given the space limitations, we emphasize the design narrative over the presentation of a specific research study. In a nutshell, the research aspect of the project consisted of teaching experiments at the two participating universities, ranging from 6 hours to 6 weeks in duration. Teaching experiments were carried out during each design iteration. Data collected included observations, interviews, surveys, tests of mathematical knowledge, and the data collected within the tool automatically. A later report will focus on empirical findings in greater detail.

1. The Enriched Math Textbook Metaphor: A Dismal Failure
Our first attempt at a Dynabook was built by digitizing some existing textbooks and “enriching” them through a mix of dynamic representations and Universal Design for Learning features (see Figure 2). In particular, we started with a Singapore Math text to which we had access and a well-known reform oriented mathematics curriculum. UDL features included a “notepad” that allowed candidates to take notes on any page as they read,
colored highlighters, text-to-speech capabilities, a glossary, and an English-to-Spanish translation dictionary. A “how do I say it?” feature gave audible examples of how mathematics terminology could be spoken. Further, building on successful prior UDL work in reading, readers were periodically asked to “stop and think” about what they were reading.

**Universal Design for Learning Principles**

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**Universal Design for Learning Principles**

This first attempt was tested by our advisory board as well as in the context of the participating campuses. We present our primary research result with this version of a dynabook without much fanfare: everyone hated it. On one hand, advisors critiqued this dynabook was “too texty,” asking instead for a more elegant design with better use of graphics and interactive features. There was a grave worry that the metaphor of the “book” was holding the project back and that the rationale for including different existing textbooks was not strong. On the other hand, advisors wanted to see a revised dynabook that was built more around the unique affordances of interactivity and digital media. They urged a smaller scope of content for the overall effort, with more attention to making the content innovative. A particular important direction was to make the dynabook better suited to use by teacher educators and candidates—to give more attention to what the users could do with it.

This feedback led the project team to do an extensive re-thinking of the project. As a consequence, the idea of starting from an existing text was dropped; we agreed to simplify the scope of content to be covered, and to focus our efforts where we could be more innovative through the creation of original content.

**2. The “Ways In” Metaphor: Discovering Our Narrative Arc**

Our new model for the Proportionality Dynabook was a matrix of 3 mathematics topics in proportionality by 4 different “ways in” to the material (see Figure 3). The reduction to 3 topics was intended to enable us to retain the idea of proportionality as a integrative middle school mathematics concept, while reducing the scope of material we would have to write. The four different “ways in” were based in part upon the strengths of the partners in writing material and in part upon their best guesses as to what would make for highly engaging digital materials for use in course. We imagined the resulting matrix of content as a collection of activities that could be flexibly realized by the teacher educators with their candidates, as they pursued the candidates learning about mathematical content, pedagogy and instruction technology. Doing these activities, we thought, could be a good way to develop candidates’ “TPACK” -- technological pedagogical content knowledge.

At the same time, the failure of the first prototype also caused us to re-think the purpose of our “book.” Most generally, we realized that a book must be written for an “implied reader” (Weinberg & Weisner, 2010) -- that is, with a sense of the activities that a reader will undertake to make sense of our digital creation. However,
whereas what a reader does while reading fiction has been well-theorized, what a successful reader does while reading mathematics is not nearly so well understood. Without a better understanding of “what success looks like” for a reader of mathematics, it would be hard to create a more supportive resource. Further, as we thought about “reading math” it became clear that it is impossible to successfully learn from a mathematics text without also writing -- reading, doing, and expressing mathematics must be deeply intertwined for learning – or even comprehension - to occur.

Although mathematics and reading are not the same kind of activity, some lessons can potentially be learned from the reading comprehension literature. One consensus theory of reading comprehension (Duke, Pearson, Strachan, & Billman, 2011) outlines eight basic activities:

1. Setting purposes for reading
2. Previewing and predicting
3. Activating prior knowledge
4. Monitoring, clarifying, and fixing
5. Visualizing and creating visual representations
6. Drawing inferences
7. Self-questioning and thinking aloud
8. Summarizing and re-telling.

Some of these have apparent analogies to mathematics, such as “activating prior knowledge,” “visualizing and creating visual representations” and “drawing inferences.” Others, such as “previewing and predicting” “self-questioning and thinking aloud” don’t feel quite right, and probably need either significant translation or replacement. One useful aspect of reading comprehension theory, however, is that it gives both a sense of the complexity of the enactment of “reading” and the sense of the arc of the process -- that it starts from a purpose and ends with a summarizing and retelling, and in the middle, there is a lot of active work with the text. What might be such an arc for mathematics?

Fortunately, our design experiments in courses with teacher educators and candidates were much more successful on this round. From these successes, a narrative arc for the Proportionality Dynabook began to emerge. Like many engaging narrative arcs, the Dynabook narrative arc featured a tension in the beginning, some alternatively frustrating and productive muddling around through the middle, and the emergence of resolution towards the end.

The most powerful beginning we found for a dynabook experience was for candidates to watch a video of a student who was struggling to solve (what should be) a routine mathematics problem. In particular, our design experiments found that one particular video was most powerful, a video of an actor pretending to be a student named “Kayla.” (Most Dynabook videos are unscripted recordings of current students; most users are unaware that some videos are of actors.) In the video, Kayla works to solve a ratio problem involving making salad dressing with a ratio of olive oil and vinegar. Kayla is not depicted as deficient in computational or procedural skill – in fact she’s quite competent. Nor is Kayla depicted as harboring some misconception or other about proportionality. Rather Kayla is portrayed as someone who is not cued by the problem - or even by subsequent queries - to engage in mathematical comprehension behaviors. Like a poor reader with a good vocabulary who believes reading and skimming are the same things, Kayla’s deficit is a kind of illiteracy.

Watching this video created a felt tension for candidates -- they wanted to help Kayla and could feel that it would be hard to do so, and thus they wanted to learn more about mathematics, pedagogy, and instructional technology as a means to creating a more satisfying conclusion to Kayla’s story. The dynabook presented her video with a transcript, and candidates could use the UDL highlighting tool to mark up important “teachable moments” where they might intervene. However, our field tests with the dynabook suggested that listening to Kayla (not reading the transcript or watching her) was specifically important. From discourse processing research it is understood that people generally find it easier to detect inconsistencies through listening than through reading. And candidates viewing and listening to the video were clearly cued to this inconsistency detection aspect of comprehension. Indeed, they mention that Kayla’s “illogicallity” and “inconsistency” was, for them, a highly salient take-away from their experience with the video.

A powerful ending for the dynabook experience was for candidates to make scripts for how they would teach with Kayla so as to help her. For this we used an existing online tool, called “Xtranormal.” Xtranormal has the tag line “If you can type, you can make movies.” Xtranormal invites a user to choose a virtual setting, choose animate avatars, and craft the avatar’s dialog (with optional stage direction). The settings offered are both recognizable (office, home, park, etc.) and richly detailed. Similarly, the characters offered are iconic, each with
quirky - but photogenic - aspect, clothing style, and accoutrement. The dialog, however, is fully in the author’s control and is read, verbatim, by a text-to-speech engine in the completed video file. Seeing and hearing their imagined dialogues come to life, so vividly, so simply, was a powerful draw for these candidates.

In courses on both university campuses, we found that the activity of making a script for teaching Kayla was intensely engaging for candidates -- as they worked on this activity, opportunities to deepen their own teaching knowledge were abundant. Through field observations and video recordings, we noted that candidates discussed their theories of Kayla, attempted to relate their observations to a research-based theory of the “stages” in learning ratio and went to both dynabook and web-based resources to find more information about how to define and teach ratio. Importantly, the candidates found hearing the scripts they wrote “enacted” by avatars both motivating and clarifying -- in listening to the script performed, they could identify unreasonable conceptual leaps in the teacher-student interaction and ways to engage with a students’ comprehension challenges. In one of the courses we observed, the teacher educator went further by asking candidates to critique each other’s scripts from the point of view of standards for mathematical practices -- and to suggest improvements that would lead to greater mathematical depth. This seemed to be a powerful way for candidates to connect the ideas in the standards to more grounded conversational moves they might make with a student.

One powerful midpoint activity, between the “video case” and Xtranormal scripting activities, was engaging candidates in solving a related challenging math problem on their own. This activity was supported by the “challenging problems” section of Dynabook. In this activity, a teacher educator asked the candidates to generate at least two ways to solve a particular challenging problem, involving ratio. In our observations, most candidates could not produce more than one solution. However, the Dynabook allowed the candidates to write and later share their solutions. When the classroom looked at the shared solutions, there was a great deal of astonishment among the candidates -- they were very surprised at the variety of solution methods they had collectively produced. Indeed, the solutions for a ratio problem varied from standard algorithms, to pictorial solutions, or more conceptual approaches. Investigating the properties of the different solutions turned out to be a very productive activity for the candidates to engage in; for example, it really opened their eyes to the potential conceptual power and relative simplicity of non-algorithmic solutions. This, in turn, influenced some of the candidates to propose teacher-student scripts for Kayla that featured problem solving approaches that were conceptually stronger and less algorithmic.

Yet, although we observed productive learning experiences for candidates using this version of the Proportionality Dynabook, the tools still seemed less than perfectly tuned to the targeted activity of the implied readers. One major problem was that Xtranormal is oriented to a talk show format for the avatars, and does not provide any easy way for candidates to include mathematical representations in how they propose to teach Kayla. We found that without any concrete referents, the tutorial dialogues were far from optimal and hard to understand. In a quick experiment, we used the spoken dialog produced by Xtranormal but added graphics to the video stream, which we drew by hand. Viewers immediately noticed the graphic increase in how productive and comprehensible the tutorial dialogue seemed. Based on insights from our field tests, we have begun to yet further re-imagine what a dynabook should be.

3. A Dialogic Journal Metaphor: Mathematical Thinking for Teaching

A potential new metaphor for the Proportionality Dynabook is that is should be a “journal” that is written by teacher candidates as they reflect in their preservice teacher education courses (Yost, Sentner, & Forlenza-Bailey, 2000). The use of the “journal” metaphor acknowledges that to “read” mathematics is to write and express mathematics too (Siegal, 1989). Journals are often also occasioned by trips; a journal can be the running notes about a journey. In this case the journey is through the Proportionality Dynabook, as they look for better ways to interact with a struggling student (depicted via a video). The practice of journaling often involves writing prompts, and a Dynabook can provide many opportunities for writing about mathematical thinking as candidates progress through our web-based digital resource.

Conventional journals, however, are often completely private objects. Dynabook as a dialogic journal is designed to be not merely a private record but a source for interaction among preservice candidates as well as their professors. To accomplish this, we imagine building on existing features in the Proportionality Dynabook that give the candidate the opportunity to share otherwise private notes by publishing them to a shared work area. We imagine generalizing this feature somewhat so that not only notes, but also all forms of work in the Dynabook would be “sharable” and thus open to further dialog among participants in the teacher education course. In past work, we have found that giving participants easy control of private-to-public transactions is often a key feature in collaborative learning spaces (Vahey, Tatar & Roschelle, 2006).
What would candidates write about? Ball and Bass (2003) introduced the term “mathematical knowledge for teaching” to recognize that K-12 teachers need specialized knowledge of mathematics, relative to their teaching assignments. For example, relative to university mathematicians, teachers often need to be able to think about the unconventional things that K-12 students do when thinking about mathematics but which are completely subsumed as taken-for-granted conventions by the time students get to the university level. Based on our field test experience, however, “knowledge” seems like too formalized and static a term for the kind of work we expect to see candidates doing; “mathematical thinking for teaching” seems more apt. That is, we would like candidates to write in their journal in ways that demonstrate their growing ability to engage in extended mathematical thinking relevant to their specific teaching assignments and relative to the thinking their students may exhibit.

While journaling typically involves writing, journaling in mathematics is more complex. As much of mathematics is understood through multiple representations, Dynabook should support creating multiple, connected representations through drawing, uploading images, audio recording, and text. Guiding questions can help candidates focus their thinking, and “sentence starters” or background images can provide hints of how to begin. A central “posting wall” can serve as a location in which candidates can share their thinking and build on each other’s work.

As we have been planning a potentially new version of the Proportionality Dynabook that leaves behind the “enriched textbook” metaphor and focuses instead on “dialogic journaling,” two specific areas of the design have received the most attention.

First, we want to more strongly feature the activity of responding to the Dynabook and encourage responses to take advantage of the flexibility of the digital medium. In particular, most digital books still have a “fill in the textbox” character when it comes to answering questions. In contrast, users of Facebook and other familiar social networking tools are becoming accustomed to being able to easily provide new information in a range of formats: text, pictures, videos, links, etc. The breadth of these options fits a UDL paradigm, however, the media types in a dynabook should more closely reflect the nature of mathematical activity. Hence, we want to feature easy ways to draw models and representations in a response area, and to call up mathematical “visualizers” for drawing a graph or exploring a geometric construction. We also want to allow spoken (audio) explanations of a mathematical idea as equally valid to textually written explanations. Our teaching experiments have found that candidates often want to write mathematics on paper and then simply take a picture of what they have done, to upload as their response.

Most importantly, we want to encourage multimodal responses rather than responding in one format only, as the Multimedia Principle (Fletcher & Tobias, 2005) and related work focuses on the power of transcoding activities for developing and demonstrating comprehension. Hence, it should be possible for a response to be a demonstration of “what I did with a virtual manipulative” along with a voice over. Or more simply, for a response to be a picture of written mathematics with a short typed explanation. Allowing for responses to be dynamic and time-based, rather than inert and static also would seem to encourage more capture of mathematical thinking.

Second, in a related effort, we want to create a tool for enacted scripts of teacher-student interactions that is better tuned to the tutorial context than Xtranormal is. Like the tool in the second dynabook version, candidates should be able to write proposed teacher-learner interactions by typing out a script. And because “hearing” the script read aloud is so powerful, both in terms of motivation but also in terms of detecting inconsistencies and ways to improve coherence, text-to-speech should be provided to enact the script. Further, the written script is useful when discussing and critiquing a particular approach to working with a student.

However, instead of emphasizing a talk show format for the enactment of the script, we prefer to emphasize the models and drawings that teacher and student may be making, referring to, and modifying as they talk. In one simple modality, the candidate who is writing the script should be able to sketch what the teacher and student may be writing on a shared piece of paper. For example, A mathematically literate reader might naturally – as a comprehension step – sketch the diagram as seen in Figure 4 and then immediately replay the result, listening for inconsistencies, ambiguities and other forms of confusion while following along with the diagram.
Rather than suggesting a from-scratch generation of the entire alternative experience the new medium could suggest an intervention-as-editing approach. It would seem more natural for an instructor to ask candidates to consider whether Kayla could be understood to be solving some problem perfectly well, just not solving the problem that was posed. They might do so by asking candidates to edit the interviewer’s statement of the problem (only) so that in the resulting script, Kayla is actually correct in her analysis.

Overall, we imagine the newest incarnation of the Proportionality Dynabook focusing on cuing candidates to reflect on their mathematical thinking and how they would deploy mathematical thinking in work with a student who is struggling to make sense of a particular mathematics problem. We imagine this dynabook as being particularly rich in ways to explore how different representations and encodings of mathematical thinking effect comprehension, which can be pursued both as an individual activity and through dialog with fellow teaching candidates. Finally, we imagine this Proportionality Dynabook as collecting examples of candidates growing ability to show how they would work with the thinking of students who are struggling with mathematical thinking, through the intervention-as-editing approach.

Discussion

In the course of three years of design experiments and teaching experiments conducted by a team of investigators at several organizations, our vision for a Proportional Dynabook has evolved considerably, moving quite a distance from the initial “enriched textbook” model. A key flaw of the initial model was that it resulted in too much text and not enough distinctively digital features. However, merely making a dynabook “more multimedia” failed to inspire us. Instead, this critique led us to think harder about the intended activities of the implied reader. Our interim model aggregated a collection of intriguing activities for teacher educators to do with their candidates, organized by a matrix of mathematical topics and “ways in” to the mathematics. Exploring this model in preservice teacher courses helped us to realize a purpose and narrative arc for a Dynabook. The purpose could be to create a unique resource to support intended activities of reading, doing, and expressing mathematics relative to the needs of struggling students. Our narrative arc started with a video of student struggling with apparently routine middle school mathematics and worked towards resolution in a script of how a candidate might engage in mathematical thinking with that same student. In the middle, the candidate might work to deepen her mathematical thinking for teaching, so as to be able to help that student.

However, the “ways in” metaphor for a dynabook did not seem to fully capture the nature of the work of candidates in the dynabook that we intuitively wanted to support. This is presently leading us to a potential new metaphor of “dialogic journaling” -- the dynabook as a resource that elicits, supports, and enables mutual commentary on candidates’ writing about their evolving “mathematical thinking for teaching.”

Relative to the 8-component reading comprehension model, we now have a better sense of the first and last component -- what the purpose for reading our proportionality dynabook might be and what the culminating summarizing and re-telling might involve. Videos of students struggling with mathematics, like that of Kayla, seem powerful for evoking a sense of purpose in candidates; they find it easy to envision themselves as working to teach students like Kayla and want to learn to do it better. Re-telling Kayla’s story as a scripted teaching episode where Kayla learns more mathematics and summarizing what they learned about mathematical thinking through this exercise seem like a good way to address the last component.
Yet, we believe we still have much to learn about what middle components in a comprehension model for a digital resource of this nature might be, and how the digital medium could best support the processes in that model. How can a dynabook draw teachers into reflecting on the potential power and pitfalls of different modalities for comprehending, expressing, and reflecting on mathematics? How can it encourage them to monitor, clarify, and improve their “mathematical knowledge for teaching?” Can the tensions between journaling as a private activity and the value of dialog with other candidates about mathematical thinking be surmounted? The analogies based on the reading comprehension literature give inspiration but not firm answers; what we need, over time, is for a deeper understanding of how teachers enhance their comprehension of mathematical thinking in relationship to potential new affordances of the digital medium.

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Acknowledgements
This material is based on work supported by the National Science Foundation under Grant No. 0918339. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.