Making a difference with attention to content, technology, and scale: A session honoring the memory of Jim Kaput

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Abstract: The theme of this year's ICLS, "making a difference," resonates with the life-work of our dear colleague, Jim Kaput, who unexpectedly passed away in summer 2005. Kaput's approach to making a difference was grounded in the Learning Sciences and distinctively attended to the nature of mathematical content, the role of technology, and the problematic of scale. In this symposium, we honor his memory by discussing the current projects of three investigators who continue to drive Kaput's vision forward. These projects address: (1) "foundations for the future" based in a deep reconceptualization of mathematical content (2) technology as representational and connectivity infrastructure that democratizes access to mathematics worth knowing and (3) scale as a challenging problematic essential to "making a difference."

Introduction

While learning scientists can present rich accounts of learning in complex contexts, convincing policy makers, teachers, and other researchers of the theoretical and practical value of our work is not a straightforward process. We must show impact at the local level while at the same time, work to have claims of more global significance. In other words, we must make clear that the learning sciences make a difference.
(from the ICLS 2006 web site)

We, like most of our colleagues, are learning scientists because we want to make a difference in the lives of learners. We find ourselves drawn together in departments, conferences, and projects because we see the scientific process as providing tools of inquiry that could unlock paths to richer, fuller learning of important mathematics and science for many more learners. The seductive allure of learning sciences lies in its potential to clarify foundational issues and inspire innovative approaches which could dramatically improve education. The shine wears off when we find that the path from insight to widespread betterment of education is anything but well-defined. "Getting to scale" is rare in education (Elmore, 1996). Too little of what learning scientists create survives the process of "fatal mutation" eloquently described by Ann Brown (Brown, 1991). Faced with this challenge, our field needs pathmakers--innovators with vision, practical wisdom, and the ability to persevere against the odds and encourage others to follow. Jim Kaput was such a person.

Kaput provided a vision of *how* the learning sciences could make a difference: by **democratizing access** to important mathematics (Kaput, 1994). Kaput saw a positive strand of development in human history in which more people could gain access to important conceptual tools (Kaput & Roschelle, 1998). Centuries ago, only a few scribes could write. Now we expect everyone to do it. The printing press commoditized books, but parallel developments in developing new genres, switching from Latin to the vernacular, standardizing printed language, and developing new pedagogical methods were required in order to democratize access to knowledge through reading. Similarly, in mathematics there was a time in which multiplication and division were very specialized skills, available only to those who could travel to particular universities. As late as 100 years ago, only 3% of students were expected to learn Algebra. Now 70% do, and we expect "Algebra for All." Today 3% of students are expected to learn Calculus. Given that we live in a time dominated by dynamism and change, Kaput felt confident that we would need to dramatically increase opportunities to learn this mathematics and we might not have a century to do it in. Hence the SimCalc project was born (J. Roschelle *et al.*, 2000).

The Learning Sciences provide deep and broad tools of inquiry. Because the tools are deep, they afford pushing foundational changes that could democratize access to mathematics worth knowing. But because they are broad, they could be applied to potentially every aspect of education. In some areas, this approach to inquiry is likely to be fruitful; in some areas it may not be. Hence, problem selection is critical. We need to understand *what* the Learning Science could contribute to democratizing access.

Kaput provided a clear vision of what the Learning Sciences could contribute: new **technological infrastructures** for representation and connectivity and **reconceptualization of subject matter** to open new opportunities to learn (Kaput, 1992, 2002). Kaput took a strong position that technology should be thought of as an infrastructural, not as particular applications and tools. Rather he saw new representations, particularly graphical and dynamic representations, as making concepts more accessible to students. He expected that these representations could be embodied in many media, devices, applications, and tools. He was interested in the new classes of representation made possible by technology (e.g. directly editable graphs of piecewise functions) and their relationship to learning. Likewise, in his last major project, Kaput saw within-classroom network connectivity as providing a new infrastructure – an infrastructure that created new structures and opportunities for classroom participation in doing and commenting on mathematics. In many presentations, Kaput used the phrase "new technology without new curriculum isn't worth the silicon its written in" to indicate his believe that reconceptualization of subject matter would be necessary to realize the learning benefits of new infrastructure. Kaput took responsibility for reconceptualizing a "mathematics of change and variation" strand from elementary school through the first year of university. He was experimented deeply, for instance, with the benefits of introducing piecewise functions much earlier in the curriculum, finding that they were intuitive to students and highlighted conceptually important contrasts in a way that students could more readily perceive.

Finally, Kaput embodied a proactive approach to the issue of **scale**. He understood scale to be a multi-dimensional problem, some of which was political, some commercial, and only a part scientific (J Roschelle *et al.*, in press). Hence, he worked with colleagues to influence standards. He engaged commercial companies to make his representations available. He built a network of researchers and research projects, so as to examine scaleability across settings. And he engaged in projects directly related to scaling up.

In this symposium, we invite presenters, discussants and the audience to engage in reflecting on Kaput's approach to making a difference: What are researchers doing now to carry forward Kaput's themes? Do these approaches make sense for a broader cross-section of the learning sciences? How could the community employ these themes to make a difference?

Symposium Agenda

We plan to open with a short introduction that recapitulates the text above, setting the context and agenda. Then we will invite three presenters, each of whom was working with Kaput on a major project when he died and is still carrying that project forward, to share the current state of their efforts to make a difference. We will then invite two discussants to each speak for a few minutes about the thematic content of the session, before opening the floor to the audience for commentary. Our discussants, Roy Pea (Stanford) and Corey Brady (Texas Instruments), will represent the Learning Sciences and commercial efforts to make a difference, respectively.

0:00 Welcome and Introduction
0:10 Presentation 1: Stephen Hegedus
0:25 Presentation 2: Dick Lesh
0:40 Presentation 3: Jeremy Roschelle
1:00 Discussants: Roy Pea and Corey Brady
1:15 Audience Participation
1:30 End

"Representational and Connectivity Infrastructure"
Stephen Hegedus, University of Massachusetts

Since the early 1990's, Kaput's vision to create dynamic visualization tools to allow students better access to core mathematics has evolved into a powerful suite of technologies with complementary curriculum materials that has had impact on students and teachers in middle and high schools, as well as undergraduate students in College Freshmen and Pre-service courses. Such work has not only made a difference on students and teachers though, but it has helped researchers and educational software developers understand new perspectives of the role of technology in 21st century mathematics education. His theoretical insights which draws deeply on the history and evolution of notation systems has led to new perspectives on software design for the purpose of enabling all students to explore multiple-linked representations of algebraic concepts, model real situations, develop problem-solving skills and discover core principles of Calculus, hitherto left for an elite population of students; ideas that help students understand the mathematics of change and variation.

Kaput's idea of a representational infrastructure has become an extremely useful model to describe dynamic vs static aspects of educational software that provides new ways for teaching and learning mathematics.

This model was deeply embedded and exemplified in his software SimCalc MathWorlds. Representational features include direct manipulation of graphically editable functions, and direct, hot links between graphically editable functions and their derivatives or integrals. Others include, connections between representations and simulations, the ability to import physical motion, and re-animate it, and the use of hybrid physical/cybernetic devices embodying dynamical systems. Since all such representational features are linked, they provide an infrastructure for a multitude of activities and learning opportunities.

Five years ago, we began to combine our software, which previously existed separately on hand-held devices and desktop computers, to work in parallel. It was not an easy task to allow functions created on an assembly language application to be reproduced in a Java environment. But it was not just about technological innovation, it was a new avenue to allow students working with our software on affordable graphing calculators to be aggregated via classroom networks into our desktop software in *mathematically meaningful ways*. We did this using various forms of connectivity but the prevalent one being Texas Instruments' Navigator system, a hub-spoke semi-wireless intranet, which can be self-configured for local, classroom based networking without an expensive network infrastructure (e.g. Internet). So now, classrooms could support connectivity without the need for a laboratory of computers with massive associated overheads and physical configurations that do not support, active, collaborative work. The SimCalc Connected Classroom was born, which allowed a distribution of cost and deliverables for maximal learning benefits; the cheapness, yet low resolution and power of many hand-held devices, with the expense but computational and representational power of desktop computers. This new system was not just about costs and affordances, but the genesis of new types of activity structures, that allowed students to contribute mathematical work all at once to a social workspace, via a teachers computer being projected on a whiteboard. There teachers can facilitate discussion to allow more students to investigate, analyze and discover mathematical relationships from observing and listening to how their work fitted into a broader set of students' work. For example, consider a class split into groups where each group has to control an actor's motion graphically or algebraically, who runs the same amount of time as a target actor (e.g. 2 ft/sec for 6 seconds; algebraically Y=2X), but you need to start at a position 3 times your group number ahead of such a target, but end the race in a tie with your target. This calls for each group to develop a different function, whose variation is in terms of slope and intercept in the algebraic form Y=MX+B, and which can be examined publicly when each group is aggregated. Such group work, calls all students to participate, not necessarily vocally, enhancing legitimate peripheral participation via mathematically enhanced communication infrastructures. It allows a student to project their self, their own identity, from a private workspace to a more collaborative social workspace. Jim believed this was a new type of mathematical learning and thinking and one that would prove to be a new educational landscape of the 21st century.

The present project that Jim and I directed has explored the impact of this representational and technological innovation on student participation and engagement as well as the impact on traditional forms of pedagogy, classroom interaction, and learning. We are deep in the midst of discovering new forms of interaction cycles that occur in Connected SimCalc classrooms, new types of questions that can be asked to help the majority of students in a classroom engage in mathematical analysis. We are also observing shifts in teaching beliefs about effective methods for instructing core mathematical ideas such as linearity, slope as rate and simultaneous equations. I shall present core activity structures that have evolved from recent work, participation structures that are evident in SimCalc connected classroom vs traditional environments, as well as data on impact on student learning and teaching practice from our collaborative analyses with our participants teachers.

"Foundations for the Future of Mathematics"

Richard Lesh, Indiana University

Any description of Jim Kaput's work should involve future-oriented themes. So, in this presentation, I'll describe a next project that we were laying the groundwork to undertake. It was intended to extend our joint vow, taken years ago, to focus on "democratizing access to powerful ideas." The next step, was to focus on what Jim referred to as "curriculum futures." And, a first step toward this project is a book that we just finished on Foundations for the Future in Mathematics Education (Lesh, Hamilton & Kaput, in press). In fields ranging from aeronautical engineering to agriculture, and from biotechnologies to business administration, future-oriented university programs increasingly emphasize the fact that, beyond school, the nature of problem solving activities has changed dramatically during the past twenty years. For example, powerful tools for computation, conceptualization, and communication have led to fundamental changes in the levels and types of mathematical understandings and abilities that are needed for success in such fields.

These observations raise the following questions:

- What is the nature of typical problem-solving situations where elementary-but-powerful mathematical constructs and conceptual systems are needed for success in a technology-based age of information?
- What kind of "mathematical thinking" is emphasized in these situations?
- What does it mean to "understand" the most important of these ideas and abilities?
- How do these competencies develop?
- What can be done to facilitate development?
- How can we document and assess the most important (deeper, higher-order, more powerful) achievements that are needed: (i) for informed citizenship, or (ii) for successful participation in the increasingly wide range of professions that are becoming heavy users of mathematics, science, and technology?

We believe that such questions should be investigated through research—not simply resolved through political processes (such as those that are used in the development of curriculum standards or tests). We also believe that researchers with broad and deep expertise in mathematics and science should play significant roles in such research and that input should be sought not just from creators of mathematics (i.e., "pure" mathematicians), but also heavy users of mathematics (e.g., "applied" mathematicians and scientists). This is because the questions listed above are about the changing nature of mathematics and situations where mathematics is used; they are not simply questions about the nature of students, human minds, human information processing capabilities, or human development.

Upon further reflection and research about the preceding issues, we gradually developed the opinion that, for most topics that we have tried to teach, the kind of mathematical understandings and abilities that are emphasized in mathematics textbooks and tests tend to represent only a shallow, narrow, and often non-central subset of those that are needed for success when the relevant ideas should be useful in "real life" situations. For example, in projects such as Purdue University's Gender Equity in Engineering Project, when students' abilities and achievements were assessed using tasks that were designed to be simulations of "real life" problem solving situations, the majority of understandings and abilities that emerged as being critical for success included were not among those emphasized in traditional textbooks or tests. Consequently, when we recognized the importance of a broader range of deeper understandings and abilities, a broader range of students naturally emerged as having extraordinary potential. Furthermore, many of these students came from populations that are highly under represented in fields that emphasize mathematics, science, and technology; and this was true precisely because their abilities were previously unrecognized. … Such observations return us to the following fundamental question:

What kind of understandings and abilities should be emphasized to decrease mismatches between: (i) the narrow band of mathematical understandings and abilities that are emphasized in mathematics classrooms and tests, and (ii) those that are needed for success beyond school in the 21st century?

Many people assume that students simply need more practice with ideas and abilities that have been considered to be "basics" in the past. Others assume that old conceptions of "basics" should be replaced by completely new topics and ideas (such as those associated with complexity theory, discrete mathematics, systems theory, or computational modeling). Still others assume that new levels and type of understanding are needed for both old and new ideas. Examples include understandings that emphasize graphics-based or computation-based representational media.

"The Problematic of Scale"
Jeremy Roschelle, SRI International

In a 4-year "Interagency Educational Research Initiative" (IERI) project, we are conducting a series of experimental trials in which hundreds of teachers will use SimCalc curriculum and software across the state of Texas. This project has brought the team of Principal Investigators (which formerly included Kaput) face to face with scale as a research problematic which is quite different from business-as-usual in the Learning Sciences.

In this project, we consider SimCalc as an instance of a coupled representational technology and re-organized curriculum, which we support with teacher professional development in order to form a testable intervention. Because SimCalc was always conceived as a curricular strand and not a full-year mathematics curriculum, we are testing SimCalc via a replacement unit in 7th and 8th grade.

The primary research question we ask across studies is about variation at the teacher level. Most learning science design projects are subject to the "Boutique Critique;" that is, "sure the intervention works with your special teachers, but I don't believe it will work with my average teachers." To counter this, we have recruited a wide variety of teachers (over 100 for the 7th grade study, from 4 regions across

Texas and representing a diversity of backgrounds, settings, and pedagogical styles). In addition to seeing if SimCalc "works," we seek to model how variations in student achievement with SimCalc materials correlate with teacher variability

Many of the critiques of the lack of experimental designs in past educational research might give the impression that researchers avoided this path because they were incompetent, biased, or lazy. Kaput always held that this was not the case; rather, he felt that carrying out such research without a very careful team who carefully documented each step could only result in dubious knowledge. Our experience has born out this conviction.

A first problematic is the disjunction between how the innovators envision their intervention working at scale vs. what can actually be tested in today's schools. Kaput always envisioned technology as infrastructural – e.g. ubiquitiously available and often used. In contrast, in the real schools we are involving in Texas, teachers still have to take students to a computer lab. This is known to be an undesirable setting for using computers, but yet it's what we can actually study. There is a chicken-and-egg problem here, because middle school math teachers are unlikely to gain access to ubiquitous technology without evidence that it works and yet one can only approximate eventually effects if teachers and students are basically unfamiliar with the technology in their everyday classroom experience.

A second problematic occurs in the design of a control condition. When the intervention is a new technology and curriculum, it is impossible for teachers to be blind to condition. A good control condition must give teachers a positive experience and some expectation that they may perform well – teachers are unlikely to motivate their students to do well if they feel they are in the conditions that's not supposed to do well. Further, we did not want to "design" the control for fear that we would be accused of intentionally or un-intentionally crippling the control. Hence, we choose to have every teacher (in both groups) attend a first professional development, which was chosen because of its high reputation for quality across Texas; then only SimCalc teachers had additional professional development. This fails to balance for additional time-on-task of teachers in professional development and hence, if we get positive results, we won't be able to discern whether it was because of more professional development or the technology-and-replacement unit.

A third problematic has to do with conflicts between ideal teacher professional development and experimental difficulty of handling teacher clustering. It is common wisdom in teacher professional development that teachers should work together within a school site or at least work in teams or pairs. This becomes challenging when working in Texas middle schools, where many schools have only one math teacher! Further, if teachers collaborate effectively, a larger n is needed and instead of a two-level design (teacher, student) one needs a three-level design (school, teacher, student) which is incredibly expensive to execute.

Yet, despite these and other difficulties, we believe that research on scale can be a valuable adjunct to ordinary Learning Sciences research. On one hand, as Kaput insisted, there will be no single "definitive" experiment that establishes whether curriculum reorganization, representational infrastructure, or new classroom connectivity capabilities are "what works." On the other hand, research on scale can overcome important credibility problems. Today, there are no large-scale, systematic, rigorous studies that measure the effects of representational technology in middle school mathematics. Given the high-level of funding for this area over many years, this creates a credibility gap that we hope our study will address. Further, only through large-scale research can we address the "boutique critique" by showing a learning-sciences based intervention can work across a wide range of ordinary settings and teachers. Finally, we can learn something about how teacher variation mediates outcomes which could enable learning sciences researchers who are designing new innovations to be more methodical about doing design research in the settings and with the teachers whose circumstances tend to diminish outcomes.

Acknowledgements

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