Commentary to Lesh and Sriraman: Mathematics Education as a Design Science

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Abstract: In this commentary, the author discusses the strengths and weaknesses to Lesh & Sriraman's (2005) ambitious proposal of re-conceptualizing the field of mathematics education research as that of a design science.

ZDM Classification: C30, D20, M10

The Lesh & Sriraman (2005) paper proposes a re-conceptualizing of the field of mathematics education research as that of a design science. This proposal is in line with Greeno, Collins and Resnick (1996) emphasis of a significant shift in the relationship between theoretical and practical work in educational research. Researchers should not only concentrate on the question of whether a theory yields coherent an accurate prediction, but also on the kind of research that includes developmental work in designing learning environments, formulating curricula, and assessing achievements of cognition and learning. Based on the reviewing process in educational research over the past few decades Schoenfeld (1999) concludes that the field of educational research has evolved to the point where it is possible to work on problems whose solutions help make things better in the practice of teaching and contribute to theoretical understanding. Research in understanding the nature of mathematical thinking, teaching, and learning is deeply intertwined with the use of such understanding to improve mathematics instruction, for the simple reason, that without a deep understanding of thinking, teaching and learning, no sustained progress on the "applied front" is possible. Wittmann (1998) describes mathematics education as a design science and calls attention to the importance of creative design for conceptual and practical innovations. The specific task of mathematics education can only be actualized if research and development have specific linkages with practice at their core and if the improvement of practice is merged with the progress of the field as a whole. Although the view of mathematics education as design discipline is emerging in the community of educational and mathematics education research the major principles and methods still have to be articulated. The Lesh & Sriraman paper contributes to this that discussion by outlining the motives for conducting design research and exploring its typical problems.

A basic motive for considering mathematics education as a design science stems from the experience that traditional approaches in mathematics education, with their focus on descriptive knowledge, which hardly provide the teachers with useful solutions for a variety of problems in teaching of mathematics. One can distinguish a broad variety of activities, with different emphases in their primary aims, under the main umbrella of design research. On a rather abstract level, one can distil a very general aim: reducing uncertainty of decision making in designing and developing educational interventions. The term intervention then serves as a common denominator for products, programs, materials, procedures, scenarios, processes and the like (van den Agger, 1999). The Design-Based Research Collective (2003) describes interventions as enacted through the interactions between materials, teachers, and learners. The design scientist faces systems that may be described as open, complex, non-linear, organic, and social. The great challenge is how to cope with the uncertainties in the complex and very dynamic contexts. As it is stressed in the Lesh & Sriraman paper complex mechanisms in education, where cognitive operations of individual learning intertwine with social processes of an organizational context, demand an extended theories and models that seek to understand the existing successes and failures of interventions. Referring to modern science, Lesh & Sriraman underline that the classical separation of subject, object and situation is no longer viable, and the design scientists are therefore involved in understanding and studying the growth of knowledge that occurs when students, teachers and researchers are confronted with problem situations involving making sense of complex situations. The design science approach to mathematics education thus raises a sequence of complex questions. I will in this commentary put some of the issues in the Lesh & Sriraman paper into perspective mainly with focus on the interactions between researchers and teachers, change in perspectives of central issues of educational research, the mathematics content and the methodology of design science. These are issues that both have the potential to set new agendas in the mathematics education research and to establish a fruitful basis for carrying forward the discussion about the proposal of the Lesh & Sriraman to re-conceptualize the field of mathematics education research as that of a design science.

Freudenthal (1991) argues that practice, at least in education, requires a cyclic alternation of research and development. In the community of mathematics education researchers it is generally believed, that the teachers do not use educational research to improve their teaching. The critical feature is here that someone outside the classroom decides what is wrong and what changes teachers have to make. Improvement of teacher-learning process requires teachers' experiences are acknowledged and build upon. Descriptions of practice by researchers are often decontextualized, and therefore make little sense to the teachers. Their considerations are much broader and more contextual than the researchers' theoretical orientation can count for. Taking the perspective of change in teaching practice and the use of research in the process Richardson (1990) argues that research should provide teachers not just with findings in the form of activities that work, but also with ways of thinking and empirical premises related to thinking and learning. In this way research becomes a basis for the development of warranted practices with which the teachers may experiment in their classroom. Teachers exercise considerable control over the decision of whether and how to implement a change in teaching practice, and any intervention should acknowledge this control, and help teachers understand and held accountable for the intervention. In design-based research researchers and teachers collaborate to produce meaningful change in the classroom practice. This means that goals and design constraints are drawn from the local context, and leads to the suggestion of a design strategy that deliberately create opportunities for the stakeholders to influence the design process and focus on adaptation to already existing practices. The collaboration across multiple settings uncovers relationships between numerous variables that come into play in the classroom context and help refine the key components of an intervention (The Design-Based Research Collective, 2003). Furthermore the close collaboration in the design processes places the teachers in direct ownership of the designs. The challenge is to maintain a collaborative partnership with the participants in the research context. According to Linn & Hsi (2000) the success of an innovation and the knowledge gained from it depend in part on being able to sustain the partnership between researchers and teachers. The design process thus calls for the cultivation of the ongoing relationships between teachers and researchers. In this context pre-service as well in-service teacher plays a crucial role. With the rationale of supporting teachers to participate in and contribute to the design process there is a clear-cut for including instructional design in teacher education. Focus should be on the significance of teachers' cognition and practical knowledge in innovative projects, and these should be considered in relation to actual or potential classroom activities. Teacher students and teachers should encounter situations where they get access to knowledge about innovation of mathematics teaching and in partnership with researchers use, share and develop this knowledge in design projects. Everything else teachers' participation in design project enlarge their pedagogical content knowledge and expands their space for action. And then there is no more to say than to cite the Lesh & Sriraman paper: truly excellent teachers always need to learn and adapt; and, those who cease to learn and adapt often cease to be effective.

Lesh & Sriraman point out that little progress had been made in problem solving research, and that problem solving has little to offer school practice. The model and modelling perspective (Lesh & Doerr, 2003) developed out of research on concept development is introduced as an emerging alternative to the traditional problem solving perspective. Design research is directed at understanding learning and teaching processes by active innovation and interaction in classroom. The innovative aspect of design research challenges common approaches to teaching and learning. Lobato (2003) addresses the central educational issue of transfer learning and argues that one's framing of the transfer problem impacts both local design decisions and larger claims. In a design experiment geared to help students' transfer of slope and linear functions to novel tasks traditional measures of transfer indicated poor transfer of learning. Reflections over the cycles of design led to a more nuanced and differentiated view of levels of transfer. From the design experiment work an alternative approach – called actor-oriented – emerged. The actor-oriented transfer perspective seeks to understand the processes by which individuals generate their own similarities between problems, and it enables the researchers to make principled design responses informed by knowledge of students' particular generalizing processes. These examples show the potential of design research to provoke and reinforce change in perspectives of central issues of educational research like problem solving and transfer of learning. In the ideal case this should result in an endeavor to identify what is salient for the students and framing a structure for learning where there is an emphasis on students learning important content, competences and skills in the context of carrying out complex tasks. Consequently a design approach to mathematics education should to call attention to Confrey's (1995) argumentation for a shift from the researcher's perspective to the student's voice: In mathematics education we have argued (..) for the importance of reconsidering the outcomes of instruction. From close listening to students we have revised our understanding of mathematics. (Confrey 1995, p. 44).

A design approach to mathematics education raises the issue of the mathematics curriculum's content as problematic. One might ask the question if contemporary mathematics education prepare the students to think mathematically beyond school. Pointing at the dramatically change in the nature of problem solving activities during the past twenty years and at the difficulties to recruit students capable of graduate level in interdisciplinary such as mathematical biology and bio-informatics Lesh & Sriraman (2005) suggest a bottom up solution. That is, initiate and study the modeling of complex systems that occur in real life situations from the early grades. This argument should be broadened to include cultural aspects. Bringing mathematics into our culture requires us to rethink our mathematics education, and what the students should know and understand. To illustrate this consider the German sociologist Ulrich Beck (1992) description of today's society as a risk society, where the definition of risk is not solely reserved to scientists or technologist. An understanding of risk is an essential cultural mission of any pedagogical institution. Coping with risk involves issues of sociology and psychology. But clearly the competence of mathematizing reality is powerful tool to cope with risk. Lesh & Sriraman (2005) open up for a more up-to-date mathematics content by suggesting a shift perspective from realizing mathematics by first teaching what is to be learned and the applying these concepts in realistic situations to mathematizing reality by first putting students in sense-makings situations where the conceptual that they develop on there own are later decontextualized and formalized. Including topics like risks, dynamic systems, self-organization and emergence with both mathematical and extra-mathematical aspects in mathematics curriculum makes the strength of mathematizing visible for the students, and at the same time they are cultivated to cope with complexity. Situating students' learning in an exploration of real world topics for a real world purpose is not the primary focus of mathematics education at primary and secondary level. It is not unfair to say, that almost all the mathematics concepts in the curriculum are ones that belong in the very academically defined mathematics curricula that dominated school mathematics after the 1960/70s reforms. Looking at the traditional mathematics curricula, one could say that in general the concepts taught are the basic concepts of mathematics. As a consequence most of the concepts studied in mathematics education research are concepts like variables, functions, differential equations and limits. Only a tiny fraction has been concerned with cross-curricular, technological, and socio-scientific content of the mathematics curricula. In view of the growth of research in mathematics education over the last decades, it is remarkable that only little attention has been paid to research on the educational relations between mathematics and other subjects. Issues related to this topic are complex, because they comprise two apparently different components, an extra-mathematical and a mathematical context. But if we as mathematics educators take the stance that mathematics has value of solving meaningful problems or even improving society, then we have to design learning environments that are meaningful to and value for the students. Putting a question to the content of mathematics education opens new frontiers for researchers in mathematics education to explore. Schoenfeld (1999) identifies curriculum as one of six sites for progress in educational research. Curriculum development provides an ideal site for the melding of theory and practice with a focus amplifying a trend toward emphasis in mathematics education on students' abilities to think beyond school. But to be fulfilled this has as a necessary condition that curriculum development encompasses research activities aiming at careful analysis, systematic description of what works and why and how it works. A key concern of mathematics education research aimed at active innovation and intervention in classrooms is to investigate the educational significance of new content areas and to carry out empirical studies to find out to what extent the key ideas may be learned by a specific group of students. What are needed here are frameworks that closely links analysis of mathematics content structure, analysis on the educational significance of that content, research on the teaching and learning processes, and the development of instructional sequences.

By pursuing the idea of a re-conceptualizing of the field of mathematics education research as that of a design science research, development, practice and dissemination are no longer strictly separated. In the Lesh and Sririman paper the importance of explaining why and how it works, and the focus on the interactions between the different components of the system. This lead us the issue of the scientific status of the data and the theoretical conclusions of the intervention. In Gravemeijer's (1994, 1998) analysis of the process of instructional development the instructional developer first carries out an anticipatory thought experiment in which it is envisioned both how the proposed instructional activities might be realized in interaction and what students might learn as they participate in them. Research is considered an interactive, cyclic process of development and research in which theoretical ideas of the designer feed the development of products that are tested in real classroom settings, leading to theoretically and empirical products, and local instructional theories. What is at stake is according to Freudenthal (1991) experiencing the cyclic process of development and research so consciously, and reporting on it so candidly that it justifies itself, and that this experience can be transmitted to others to become like their own experience. This indicates that design studies often rely on narrative accounts as data for modifying theory, communicating empirically grounded claims and assertations and to enhance the likelihood of replicability (Cobb et al., 2003). The design approach necessarily encompasses studying alternatives to an actual practice. Skovmose & Borba (2000) argue for investigating alternatives in such detail that they can confront what might be considered as a given current situation. They propose a framework, which is focused on investigating alternatives to the current situation, using pedagogical imagination to create imaginative situations. A pedagogical imagination means being involved in a process of conceptualising a different situation by acknowledging critical features of the current situation. However, the educational situation constrains the pedagogical imagination. Therefore an arranged situation is organised trough practical organisation, which means to negotiate a specific situation with specific constraints. The arranged situation is certainly an alternative to the current situation. It is also different from the imagined situation, but is has been arranged with the imagined situation in mind. Observations are linked to the arranged situation and are limited by this situation, but part of the analysis concerns the imagined situation. The notion of critical reasoning is introduced as the analytical strategy aiming at investigating imagined educational situations based on studies of particular arrangement representing the imagined situation. The approach of Skovmose & Borba (ibid) goes beyond process-sequence strings and coded protocols in research methodology and thus has the seeds of a fruitful answer to some of the challenges in design research with respect to evaluation methodology.

During the last decades extensive work has been done on improving mathematics education. The outcomes of these efforts have been only moderately successful, and apparently we still need to find better ways of teaching mathematics. One could argue that such better ways could be best derived from the application of results from mathematics education into practice. More than most of the other research approaches in mathematics education, a design research aims at making both practical and scientific contributions. A re-conceptualization of mathematics education has not yet crystallized by any means. Many new experiences will be necessary and importance of exchanging views and experience. I have in this commentary to the Lesh & Sriraman paper focused on the issues of the interactions between researchers and teachers, change in perspectives of central issues of educational research, the mathematics content and the methodology, which in my view might be fruitful basis for carrying forward the discussion initiated by the Lesh & Sriraman paper. And the emphasize with a reference to pragmatists like Dewey and Pierce that it is arrogant to assume a single "grand theory" will provide adequate basis for decision-making for most important issues that arise in life should of its own accord invite to a carrying forward the discussion.

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