Learning and Instruction 25 (2013) 13–23

Contents lists available at SciVerse ScienceDirect

Learning and Instruction

journal homepage: www.elsevier.com/locate/learninstruc

Collaborative learning with multi-touch technology: Developing adaptive expertise

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ARTICLE INFO

Article history:
Received 26 February 2012
Received in revised form
21 October 2012
Accepted 22 October 2012

Keywords:
Adaptive expertise
Collaborative learning
Group work
Computer-supported collaborative learning
Mathematics learning

ABSTRACT

Developing fluency and flexibility in mathematics is a key goal of upper primary schooling, however, while fluency can be developed with practice, designing activities that support the development of flexibility is more difficult. Drawing on concepts of adaptive expertise, we developed a task for a multi-touch classroom, NumberNet, that aimed to support both fluency and flexibility. Results from a quasi-experimental study of 86 students (44 using NumberNet, 42 using a paper-based comparison activity) indicated that all students increased in fluency after completing these activities, while students who used NumberNet also increased in flexibility. Video analysis of the NumberNet groups indicate that the opportunity to collaborate, and learn from other groups' expressions, may have supported this increase in flexibility. The final phase of the task suggests future possibilities for engaging students in mathematical discourse to further support the development of mathematical adaptive expertise.

1. Introduction

Developing fluency and flexibility with mathematical constructs and skills is a key goal of primary education in the UK, aiming to provide students with a solid basis to understand more complex mathematics concepts in later years. However, while fluency with the application of standard procedures can be attained through sustained practice (Doyle, 1983), developing flexibility is more complex (Greeno, 1991). In this paper, we describe a tool, NumberNet, that uses computer-supported collaborative learning activities to foster mathematical flexibility and reasoning, through a series of small group and whole class activities, contrasting its use with standard classroom activities to explore whether collaborative engagement in mathematics practice can support the development of flexibility.

Mathematics education in the primary years aims to teach students basic numbers and calculations and to prepare them to learn more complex mathematics by developing an understanding of arithmetic and numerical principles. In order to achieve these two goals, students need to become adept at applying standard procedures to anticipated problems, and also understand the range of possible procedures and strategies they can use when they encounter novel problems (Baroody, 2003). While developing 'number-sense', both flexibility and accuracy are seen as desirable outcomes for students learning mathematics, and are behaviors that are seen in adult mathematicians, our understanding of how a deep conceptual understanding of mathematics develops, and its relationship to mathematical practice, is not complete (De Haene, 2011).

Preparing students to engage in more complex mathematics requires that we consider what mathematical expertise looks like. Researchers differentiate between two types of experts: routine experts, who can expertly apply formulae or procedures, although they lack a deep understanding of the structure of the discipline, and adaptive experts, who can flexibly approach novel problems and apply a range of solutions. Initially described by Hatano and Inagaki (1986) to differentiate between application of procedural and conceptual knowledge, the concept of adaptive expertise has become a challenge to those developing educational activities which support students in understanding the complexities of mathematics (De Smedt, Torbeyns, Stassens, Ghesquière, & Verschaffel, 2010).

Conceived as the application of conceptual understanding of a discipline, adaptive expertise has been described as being beyond routine expertise, developing once routine expertise has been established (Salomon & Perkins, 1989), or as a different form of expertise. Schwartz, Bransford, and Sears (2005) hypothesized that adaptive expertise, rather than being further along the expertise continuum than routine expertise, was a form of expertise that

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http://dx.doi.org/10.1016/j.learninstruc.2012.10.004

brought a dimension of innovation to routine expertise. This framework places innovation and efficiency as orthogonal constructs, and proposes that adaptive expertise emerges when learners balance efficient use of procedures with an innovative approach to problems. Thus, preparing students to be adaptive experts requires that they have opportunities to practice the application of procedures, and that they encounter situations within which they need to innovate and identify new solutions (Inagaki, Hatano, & Morita, 1998). The concept of adaptive expertise as the balance between innovation and efficiency in problem solving aligns with the goals of primary mathematics, where fluency and efficiency with mathematical procedures needs to develop alongside a flexible, more innovative approach to problem solving.

Research on developing adaptive expertise in mathematics finds that primary-aged students can be supported in developing an understanding of mathematical concepts through exploration. Markovits and Sowder (1994) designed a three-month long curriculum for seventh-grade students, that focused on number magnitude, mental computation and computational estimation. The instruction provided opportunities to explore the relationships between numbers and a range of operators. When compared to students using a traditional curriculum, the students in the experimental condition were more likely to choose solutions to problems that indicated number-sense, differences that were still identified in a post-test six months after the instructional period had ended. Due to the nature of the instruction, as well as its relative brevity, the authors conclude that the students in the experimental condition were unlikely to have learned new procedures during the instruction, but rather, the experimental condition encouraged the development of a deeper conceptual understanding of the content they had already acquired, which allowed them to solve novel problems.

Similarly, Martin and Schwartz (2005), in studies teaching fractions to nine- and ten-year-olds, found that using relatively unstructured manipulatives (e.g., tiles) rather than well-structured manipulatives (e.g., pie pieces), resulted in better transfer to new problems. Giving students the ability to reconfigure the manipulatives meant that it took longer for the students to grasp the concepts initially, but supported a deeper understanding of the concepts, which they could then apply in novel situations. This suggests that rather than focusing on the most efficient way to teach, students should be given opportunities to make sense of the concepts, in order to prepare them for more complex problem solving.

While cognitive psychology has begun to unpick the nature of how to support the development of adaptive expertise in the individual learner, the concept of adaptive expertise, as defined by Hatano and Inagaki (1986) is inherently situated within the environment in which it is developed and used. The process of moving from novice to expert was described by Hatano and Inagaki as "novices become adaptive experts – performing procedural skills efficiently, but also understanding the meaning and nature of their object" (1986, pp. 262–623), indicating that adaptive expertise cannot be separated from the context in which it is applied. Although cognitive approaches describe the move to adaptive expertise as one that requires deep conceptual understanding, it is clear that this conceptual understanding must be rooted in an understanding of the practices of the discipline. Thus, understanding the development of mathematical adaptive expertise also requires an understanding of the environment within which the learning of mathematics occurs (Hatano & Oura, 2003; Verschaffel, Luwel, Leuven, Torbeyns, & Van Dooren, 2009).

In 1988, Hatano described conditions under which the deep conceptual knowledge necessary for adaptive expertise was developed. Recognizing that the process of "constructing, elaborating or revising" a model (p. 57) is essential for the development of adaptive expertise, he noted the importance of motivation to engage in this process. This motivation comes from being surprised by incorrect predictions, perplexed by competing ideas or becoming aware of a lack of coordination between pieces of information. Hatano indicates that students must encounter novel problems, be encouraged to seek comprehension and be free of immediate drives for external reinforcement, which hinders the ability to focus on the complexity of problems. Additionally, Hatano notes the importance of dialogue between learners, which introduces more instances of surprise, perplexity and disco-ordination. These conditions describe the importance of environmental supports that contribute to the development of adaptive expertise.

Yackel and Cobb (1996) used the term socio-mathematical norms to describe what counts as appropriate mathematical discourse, which regulate the forms of mathematical argumentation and opportunities to engage with mathematical concepts in a particular classroom. Working with second and third grade teachers, they explored the development of these norms in classrooms committed to inquiry-based mathematics teaching. The authors report that providing the students with opportunities to make sense of the arguments of their peers, drawing on the classroom norms to reach higher levels of mathematical reasoning, supported increased sophistication and flexibility in their use of mathematical constructs. This emphasizes the importance of the learning context and opportunities to engage in discussion about mathematics as important elements in the development of mathematical adaptive expertise.

The context within which mathematical adaptive expertise develops was described in detail by Boaler, studying a project-based mathematics class. Boaler (1998, 2000) argues for the importance of understanding not only how to teach the procedures that students need to learn, but also focusing on the mathematical practices that they develop while they are learning. She argues that the use of collaborative problem-based learning allowed students to develop a rich understanding of the discipline of mathematics, and become engaged in the practices of mathematics, as well as the procedures. It is in understanding these practices, and applying and adapting mathematical procedures, that the students were prepared for standardized tests and also for the adaptation of mathematical knowledge to real-life situations, which can be identified as adaptive expertise.

There is a long history of using collaboration to support the learning of mathematics, (e.g., Barron, 2003; Esmonde, 2009; Slavin & Lake, 2008; Webb & Farivar, 1994). Many of these studies indicate that the process of collaboration can effectively support mathematical problem solving, and that this learning can be transferred to new tasks. As noted by Hatano (1988), the motivation to engage deeply with content, engaging in the types of learning that lead to adaptive expertise, can come from situations where the learners are required to reconsider their own conceptions of the material. Research on collaborative groups suggests that they can provide an opportunity for this type of engagement with content, as students encounter the ideas and questions of members of their group, forcing them to reconsider their own understanding, or consider the content in a deeper or more complex manner. However, for the most part, these studies focus on the workings of single groups of learners (c.f. Tolmie et al., 2010), with little opportunity for groups to learn from other groups within the same classroom, despite the recognition of the centrality of the classroom discourse and interactions in developing mathematical knowledge (Greeno, 1991).

By drawing on these cognitive and socio-cultural perspectives of the development of adaptive expertise, and our understanding of the value of collaborative learning to engage students more deeply