Engaging Middle School-Aged Students in Classroom Science and Mathematics: Implications for Design and Research

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Abstract: A critical educational challenge and core issue for the ICLS 2012 theme of "the Future of Learning," is how to keep students, particularly those who attend the most under-resourced schools, engaged in science and math as they progress through secondary school. The four papers in this symposium discuss key issues, challenges, and progress around interest and engagement in science and math for students in grades 5 to 7. From a range of theoretical and methodological perspectives, the panelists discuss what interest and engagement are as research constructs; some of the design principles, key features of instructional materials, and contextual factors that trigger and shape interest and engagement; how learner characteristics influence the ways students select or respond to opportunities to engage; the roles that interest and engagement play in learning; and issues of measurement. This 90-minute session will include both formal presentations and moderated discussion among the panelists and audience.

Symposium Overview

A critical educational challenge is how to keep students, particularly those who attend the most under-resourced schools, engaged in science and math as they progress through secondary school. Motivation and engagement are essential to learning at all ages (National Research Council, 2000), yet it is well-documented that students' interest and enjoyment in both science and math generally decline as they move from primary to secondary school (e.g., Hidi & Harackiewicz, 2000; Krapp, 2006; Speering & Rennie, 1996; Eccles & Wigfield, 1992; National Center for Education Statistics, 2006). The late primary / middle school years are a particularly important and vulnerable transition point in the school trajectory, as concepts become increasingly difficult and abstract (Nathan & Koellner, 2007; Leinhardt, Zaslavsky, & Stein, 1990). Many students begin to lose interest in science and math, fall behind in achievement (Oakes, 1990), and consolidate motivational attitudes (Eccles, Wigfield, & Schiefele, 1998). Declining interest is of special concern for urban inner-city students who face challenges of poverty, cultural differences, and language.

In the US, the National Research Council-commissioned book, *Engaging Schools: Fostering High School Students' Motivation to Learn* (National Research Council & Institute of Medicine, 2004), reports on a federal charge to review and synthesize the broad spectrum of educational research to establish a set of recommendations for the educational community for how to promote and maintain student engagement and genuine improvements in achievement throughout the high school years. This symposium focuses on the Committee's first recommendations, that "courses and instructional methods be redesigned in ways that will increase adolescent engagement and learning" (p. 214).

This charge is highly relevant to the international ICLS 2012 theme of "the Future of Learning," in particular to the key prototypic research questions:

- How can the energies and motivations that accompany a learner's interests be matched with learning resources to enable productive learning pathways?
- How can teachers productively create teaching and learning environments that support the needs of learners of diverse linguistic, cultural and economic backgrounds?

These questions indicate the need for deep understanding of motivation as a research construct and its implications for design: What are key aspects of instructional materials and context that trigger and shape interest and engagement? How do learner characteristics influence the ways students select or respond to opportunities to engage?

The four papers in this symposium provide complementary approaches to addressing these issues in the teaching of science and mathematics, especially for students in the late primary / middle grade years. The two papers by Pressick-Kilborn and Gresalfi describe design principles and design research undertaken with the aim of developing and understanding specific instructional affordances for motivation in science and math classrooms. Renninger & Bachrach report on findings addressing the relation among triggers for interest and learner characteristics in an out-of-school science program for at-risk youth, and Shechtman et al. consider issues of operationalization and measurement in a study of engagement as a multidimensional construct in the urban mathematics classroom. The papers represent a range of theoretical perspectives, rooted in both sociocultural and psychological approaches; a range of methodological approaches, including design research, qualitative case studies, and psychometrics; both formal and informal instructional contexts; technology-based curriculum and curriculum less reliant on technology; and settings in both the US and Australia. Furthermore, within these issues, the papers speak to a number of themes important to the ICLS community: collaborative learning, metacognition and self-regulation, developing flexible understandings that can be used beyond formal schooling and throughout life, and the capabilities of interactive technology and computational models for supporting STEM learning.

The 90-minute session format will be as follows. The first hour will be formal presentation; each paper will be presented for 15 minutes. The last half hour will be dedicated to a discussion among the panel and a moderated discussion with the audience. The discussant is Richard Walker, whose research interests center on ways of enhancing the learning, motivation, and academic achievement of students at all levels of education. His work investigates from a sociocultural perspective learning in electronic learning environments designed to support collaborative and cooperative interactions among students, the use of textbooks and other learning resources, after-school homework support, and identity formation. He will pose questions to the panelists about the design implications from their findings regarding the prototypic questions, for example, (a) the match between middle school students' interests and learning resources; and (b) how teaching and learning environments might productively address the needs of learners of diverse linguistic, cultural and economic backgrounds.

Paper 1: Instructional Design Principles for Engaging Students in Learning Science and Fostering Interest Development

Kimberley Pressick-Kilborn

Problem and Theoretical Rationale

A number of studies have reported that while students have a great deal of enthusiasm for science in the primary years, interest and enjoyment generally decline during the early years of learning science in secondary schools (Hidi & Harackiewicz, 2000; Krapp, 2006; Speering & Rennie, 1996). This finding leads to the question of what it is that makes primary science engaging and interesting. More specifically, what features of primary contexts for science learning contribute to creating, maintaining and developing student engagement and interest?

The focus of this paper is the articulation and illustration of guiding instructional principles for supporting the development of students' interest in learning science. The project was framed from a Vygotskian sociocultural perspective, which emphasises the social origins of learning and motivation (Walker, Pressick-Kilborn, Sainsbury & Arnold, 2004; Walker, 2010). Strengths of adopting a sociocultural perspective lie in the emphasis on studying interest as it develops in authentic learning contexts over time, enabling the relationship between situational and individual aspects of interest to be considered as inclusively separate (Valsiner, 1998) so that a study of the total activity is maintained.

Method

The principles were developed as part of a qualitative, classroom-based project that drew on a design-based research methodology (Brown, 1992; Guthrie & Alao, 1997), aimed at informing and extending both theory and practice. Seven guiding instructional principles were established at the outset of the research, informed by the literature relating firstly to student motivation and interest (for example, Mitchell, 1993; Paris & Turner, 1994;

Guthrie & Alao, 1997; Bergin, 1999; Ainley, 2001), and secondly to classrooms as learning communities (Bereiter & Scardamalia, 1993; Brown, 1997; Collins, 1998). Two science learning units were subsequently designed in collaboration with a classroom teacher, guided by these principles, and team-taught in a grade 5 classroom in Sydney, Australia. Detailed researcher field notes were recorded for observations of class activities, student engagement and interest, as students participated in weekly science lessons over 6 months. Students shared self-reports of their interest through charting retrospective interest trajectory graphs and semi-structured interviews were conducted with six focus students at different time points during the study.

Results

The key features of the learning units that contributed to creating a community of learners, designed to create and support interest and engagement in science and technology, were identified and considered in relation to (1) physical features of the classroom context (classroom layout, access to materials), (2) features to support social interaction within and beyond the classroom (grouping structures and strategies, access to experts in the wider community) and (3) pedagogical features (opportunities for hands-on involvement, varying degrees of choice, reflection on learning, interactive noticeboard). Individual student interest trajectory ratings were collated to create a class mean trajectory of interest development, which revealed patterns of interest in the classroom learning community. Interest peaked during engagement in hands-on investigations and design and make activities with multiple pathways for task completion and possibilities for negotiation. Interest peaks also were evident for guest speaker presentations and an excursion. Troughs were observed for class discussions, when there was relatively more passive engagement of students who were listening to peers, more limited opportunities for active participation and greater teacher control.

Discussion and Implications

The seven instructional principles articulated at the outset of the research related to the organisation of science learning units in three distinct phases, and emphasised the importance of active student engagement in hands-on tasks with possibilities for choice. The principles also supported the inclusion of both individual and collaborative activities, as well as opportunities for engagement with topics and issues of concern to the broader scientific community, and contact with domain experts and communities of practice beyond the classroom. In addition, the principles guided the teacher to share emotions during the learning process and to lead the learning as a more expert learner, whilst also fostering student reflection on the learning process. My researcher perspective as a participant observer in that classroom led to the refinement, elaboration and extension of the initial guiding design principles. In particular, three additional principles were developed, focusing on play, imagination and the physical layout of the classroom.

The focus of this paper on guiding instructional principles has clear implications for classroom practice and more specifically, science curriculum design. The principles are illustrated by drawing on data gathered in the classroom-based research project, with the focus on elaborating the relationships amongst interest, engagement and learning.

Paper 2: Designing to Support Critical Engagement with Content

Melissa Gresalfi

Problem and Theoretical Rationale

In this paper I describe a set of design experiments that were undertaken with the goal of supporting a particular form of engagement that we call *critical* engagement, which involves making intentional choices about which procedures to leverage in order to support particular claims.

The past twenty years have brought technological innovations that have changed the world as we know it. Continuous access to online information has supported a transformation of the relationship between individuals and knowledge; with information so readily accessible, people have been repositioned to move beyond *acquisition* of facts to consider when to access those facts, interrogate them, and integrate them into activity. For these reasons, knowledgeable participation in mathematics must involve more than proficiency using key procedures. Instead, knowledgeable participation must involve engaging in acts of decision-making, determining which procedures enable the resolution of defensible solutions, how, and why.

It is clear that supporting students to engage with mathematics in this way is not simply a matter of learning more mathematics content. Instead, it is crucial that students have opportunities to learn new content in ways that are consistent with how we actually want them to use that information (Boaler, 2000; Bransford & Schwartz, 1999; Cobb, Stephan, McClain, & Gravemeijer, 2001; Engle, 2006; Greeno, 1991; Lave, 1997). When creating new curricula, it is therefore crucial that designers attend not just to the content goals of the unit (the mathematical ideas you want students to learn and understand), but also participatory goals of the unit (how you hope students will engage). This does not mean that becoming a successful engineer, for example, requires learning all mathematics at the elbow of a practicing engineer. Instead, this suggests that the kinds of *practices* that a practitioner is expected to leverage (such as experimenting, reviewing, collaborating, justifying, testing, and inventing) are the practices engaged in during the learning experiences.

Data Sources and Methods

This paper presents two rounds of a design cycle of a statistics unit, created in the context of an online, interactive videogame called Quest Atlantis. The design experiment was conducted with the same teacher over two years, focusing on two different 5th grade math classes. For both studies, the entirety of the two-week unit was captured with videotapes of whole class interaction, small group discussion, and individual interviews. In addition, students' submitted work was collected and coded for accuracy and for evidence of critical engagement.

Results and Significance

Examining the design history of the unit, this paper demonstrates how iterative refinements of the unit supported increasing critical engagement with the content, and specifically, the importance of fostering both *intentionality* and experiences of *consequentiality* in the designs. Finally, the paper considers the implications of the lessons learned for this targeted intervention for our understanding of how elements of design support students' mathematical reasoning more generally.

Paper 3: Design Implications from Study of Potential Triggers in an Out-of-School Biology Workshop

K. Ann Renninger & Jessica E. Bachrach

Problem and Theoretical Rationale

For educators, an essential question is how to pique, or trigger, the interest of learners. However, little is understood about how triggering really works outside of the experimental setting. A working assumption among motivation researchers is that potential triggers for interest result in engagement even though research findings sometimes suggest otherwise (e.g., Durik & Harackiewicz, 2007). Moreover, the assumption that potential triggers result in engagement presumes that all learners perceive and respond to potential triggers in the same way—a point that has also been challenged (e.g., Bartlett, 1932; E. J. Gibson, 1982; J. J. Gibson, 1950, 1977, 1979; Herrenkohl, Tasker, & B. White, 2011; Norman, 1999). Better understanding of the triggering process is needed to begin to explain when and why potential triggers for interest are effective.

In order to consider the relation between potential triggers for interest and learner engagement, as well as the relation between engagement and learner characteristics, findings from two studies of the activity of eight inner-city middle school participants in an out-of-school biology workshop will be described. Study 1 addresses the identification and generalizability of potential triggers for interest across activities. Study 2 is a post hoc analysis that explores the relationship between triggers for interest and learner characteristics.

Participants

Eight youths (3 males, 5 females) participated in the biology workshop. They were African-American or racially mixed and ranged in age from 9-12 years; mean age was 10.5 years. The youth were participants in a rigorous choral training program for inner-city youth and were enrolled in the workshop as a summer enrichment activity. They had had no previous experience with formal instruction in science and they were identified as being in the earliest phase of interest development.

Data Sources and Methods

Informed by grounded theory (Charmaz, 2000; Strauss & Corbin, 1998), potential triggers for interest were tracked using participant observation notes collected as part of a larger project focused on participant learning and motivation in an out-of-school, inquiry-oriented biology workshop for inner-city youth. Multiple additional sources of data (workshop artifacts, participant interviews, caretaker interviews, and educator reports) were available to the researchers as reference material for each of the two studies. Analyses for both studies were undertaken at the level of the activity and/or the group.

Each of the studies to be reported targeted participants' behaviors during ongoing workshop activity (Stake, 2005); other studies of the workshop have focused on individual participants. Categorical directed content analysis (Hickey & Kipping, 1996; Hsieh & Shannon, 2005; Potter & Levine-Donnerstein, 1999) was used for the first part of both Study 1 and Study 2. This approach involves using existing research and theory to inform data reduction, in addition to allowing identification of emergent categories for coding. The categories identified in Part I of each study were then used to code data in Part II of each study.

Potential Triggers for interest identified based on a review of the literature and tracked for purposes of analysis included affect, autonomy, challenge, character identification, computers/technology, group work, hands-on activity, instructional conversation, novelty, ownership, and personal relevance.

Findings and Significance

Taken together, findings from both studies confirm that learners do not perceive and respond identically to potential triggers for interest and provide insight into the circumstances affecting when potential triggers will and will not work for learners who are new to science. They indicate that the triggering process is nuanced and is informed both by the features of the activity and the readiness of the learner to pick up on potential triggers. Findings from Study 1 indicate that triggers examined in experimental studies could be identified in the naturally occurring workshop setting. Furthermore, the same triggers could be identified in multiple activities, although they may or may not work for all learners at all times. Moreover, some activities included multiple triggers.

As in studies from work on situational interest, the present findings indicate that when triggers work, attention is captured. In this sense, triggering enabled engagement (Fredricks, et al., 2004) and was often dependent on other people in the environment, the design of activities, or, as reported in Study 1, serendipity such as when a participant walked into a spider's web. In contrast to discussions suggesting that situational interest might be expected to work the same way for all learners (e.g., Hidi & Berndorff, 2001), the present findings suggest that the process of triggering is complex and idiosyncratic, and that knowledge of the learning environment and the learner may be essential for predicting whether potential triggers will work.

Findings from Study 2, furthermore, underscore that learner characteristics are likely to affect when and how potential triggers work. While this notion is not new, Study 2 represents an initial attempt to systematically investigate this relation and to do so in a naturally occurring context with all of its complexity. A number of previously unreported relations among potential triggers and learner characteristics surfaced. In particular: (a) Some learner characteristics were found to be more relevant to some triggers than others (e.g., sociability appears most likely to influence whether group work works as a trigger for interest); (b) The success of some potential triggers was found to always be tied to particular learner characteristics (e.g., personal relevance was always affected by awareness); (c) Furthermore, potential triggers were found to be affected by different numbers of learner characteristics (e.g., affect, challenge, and group work were affected by all of the identified learner characteristics).

Paper 4: Unpacking the Black Box of Engagement: Cognitive, Behavioral, and Affective Engagement in Learning Mathematics

Nicole Shechtman, Britte Cheng, Patrik Lundh, & Gucci Trinidad

Problem and Theoretical Rationale

Keeping students engaged in mathematics as they progress through secondary school is a critical national educational challenge for practitioners and researchers. It is also called out in many recent national policy documents (e.g., *Engaging Schools* [National Research Council& Institutes of Medicine, 2004], *National Mathematics Advisory Panel* [NMAP, 2008], *Adding It Up* [Kilpatrick et al., 2001]). However, "engagement in mathematics learning" is still somewhat of a black box—the field is grappling with a gap in our understanding of what engagement in mathematics truly is, how to measure it, what its relationships to learning are, and how we could leverage what we understand to increase engagement for all students.

The goal of the Math Engagement Project (MEP) is to examine ways to unpack this black box. MEP is an exploratory research study of middle school mathematics learning and engagement to build theory and instrumentation around engagement in mathematics learning—which we treat as a complex, multidimensional, context-specific construct. We will present findings with respect to a theoretical framework we are developing to capture the dimensions of engagement in math learning as it is embedded in the classroom as an activity system. In a review of the broader literature on school engagement, Fredricks et al. (2004) describe several dimensions that are implicit within "engagement." We apply this specifically to the domain of mathematics learning, teasing apart three components: (a) behavioral engagement (e.g., being on-task), (b) affective engagement (e.g., enjoying or being interested), and (c) cognitive engagement (e.g., doing the cognitive work). Within the cognitive space, there are also a variety of "ways" of engaging generally (e.g., memorizing facts vs. solving novel problems) and specifically with mathematical content (e.g., critical [see Paper 2] vs. procedural vs. conceptual). We also distinguish engagement at two different time horizons: (a) "dispositional engagement" over a long period of time (e.g., engagement in secondary math), and (b) "proximal engagement" in the moments of instruction (e.g., engagement in today's math lesson).

We use this framework to unpack the elements of engagement and learning of middle school students (ages 12-13) in the classrooms of two teachers teaching a 4-week unit on rate and proportionality. In prior large-scale RCTs, this unit, which integrates curriculum and the interactive, dynamic software SimCalc MathWorlds, was shown to promote gains in conceptual understanding for a wide variety of students (see Roschelle et al., 2010). However, while learning gains overall were robust, there was also substantial variation between students—indicating that not all students engage with the unit to the same extent or in the same ways. In the current study, we use multiple methods to examine individual students' behavioral, affective, and cognitive engagement during several lessons in the unit. We seek to characterize the range of engagement and examine how it may be shape the mathematics that students learn. Furthermore, we examine how the ways individual students engage may be shaped by (1) the dispositions students bring to the unit, and (2) the affordances for engagement provided by the curriculum and the teachers.

Methods

For the 302 seventh-grade students across the two teachers' 11 classrooms, sources of data include: (1) pre-unit survey of attitudes and dispositions toward learning and mathematics (e.g., achievement orientation, interest in mathematics, mathematical confidence and anxiety, school engagement); (2) unit pretest and posttest to measure baseline knowledge and learning gains for the unit's mathematical content; (3) survey administered multiple times throughout the unit to capture students' self-reported behavioral, affective, and cognitive engagement in the lessons; (4) teachers' report of students' behavioral, affective, and cognitive engagement for a subset of 98 students; (5) analyses of written mathematical work for evidence of cognitive/mathematical engagement; and (6) classroom observations focused on the mathematical discourse. Additionally, 11 case study students (7 girls, 4 boys) were interviewed before, during, and after the unit to investigate their engagement and learning in greater depth. This paper will focus on the behavioral, affective, and cognitive engagement of the students over the course of the unit, using the 11 case study students as illustrative examples. We draw from these multiple sources of data to characterize the different ways students engage, how their engagement relates to their learning, and the dispositional and contextual factors that shape their engagement.

Preliminary Results and Discussion

The context of the study was a suburban area in Northern California. The school has less than 10% of students qualifying for the free or reduced lunch program, and the majority of students are Caucasian or Asian/Pacific Islander (Note that we are in the process of recruiting for the next study which will focus on students in high-poverty, high-minority schools). The 11 classrooms across the two teachers represented the remedial and grade-level pre-algebra tracks (more advanced students had a different teacher). Not surprising in this context, student attendance was high and behavioral disruptions were relatively low. Both teachers taught with high fidelity to the workbook. On average, students reported a relatively positive classroom climate, in terms of both teacher and student support. The mean student pretest and gains were slightly above the average of the RCT treatment group, which represented a wide variety of classrooms across the state of Texas.

Within this context, the 302 students represent a range of prior achievement levels (as measured on the pretest) and prior attitudes and dispositions toward learning and mathematics. While most of the students tended to be behaviorally engaged (i.e., on task) much of the time, preliminary findings suggest marked differences in the ways students engage affectively and cognitively. Affectively, while some students' engagement is marked by interest and enthusiasm, other students' is marked by boredom, anxiety, or indifference. Cognitively, while some students engage in building their own knowledge as the curriculum was intended through inquiry with the software and asking questions, other students appear quite satisfied to passively absorb the lessons, while others are strongly disaffected and simply trying to get by. Preliminary findings also suggest that these ways of engaging may be mediated by dispositions students had reported at baseline (e.g., how they see themselves as learners in the classroom, achievement orientation as mastery vs. performance, mathematical self-efficacy), the ways in which the teachers scaffold the lesson, and opportunities to interact productively or unproductively with peers. For example, the more passive cognitive engagement was observed in a highly math-anxious student in the classroom of the teacher who scaffolded the lesson in a way that emphasized correct answers. Findings also suggest that these ways of engaging have consequences for the depth of conceptual understanding that students attain.

These and other themes will be discussed with respect to the broader literatures on engagement and motivation. We will explore implications for the measurement of engagement and how to find leverage points for developing ways to support engagement in learning mathematics.

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