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DIGITAL COLLABORATIVE ENVIRONMENTS: CONNECTING THEORY OF INSCRIPTIONS TO THE DESIGN AND DEVELOPMENT OF STUDENT RESOURCES

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The paper aims to report on research efforts to design and develop digital collaborative environments for middle grade students (11-13 years old) in mathematics classrooms. Specifically, we report on how a theory of inscriptions can be useful for developing student resources to promote student learning of mathematics. The report focuses on the emerging entailments of constructing and sharing inscriptions as it relates to student's real-time collaboration in a digital platform.

INTRODUCTION

A situative perspective of learning (Cobb, 2002) shifts attention from focusing on representations of the individual mind towards viewing representations as a social practice. Representing activities are "part of networks of social practices that take their characteristic shape and meaning from the contexts, purposes, and functions of their use" (Roth & McGinn, 1998, p. 46). The term, inscriptions, refers to material representations of one's thinking on paper or on the computer screen that are embedded in the networks of social practices. Examples of inscriptions may include text, graphical displays, tables, equations, diagrams, maps, and charts. 'Inscriptional practices' is one of the important disciplinary practices in mathematics (Kindfield & Gabella,2010) and refers to the use of inscriptions for productive behaviors such as expressing, interpreting, explaining, predicting, critiquing , reasoning, exemplifying, and communicating mathematical and scientific ideas (Wu & Krajcik, 2006). Understanding of inscriptions and inscriptional practices are powerful because they can be used not only for analytic purposes but also for designing educational environments and curriculum materials. The latest technological advancement and digital pedagogical innovation allow for additional affordances of constructing, sharing, and using inscriptions. These affordances can potentially enhance the 'inscriptional practices' and help in mathematical sense-making. In this paper, we highlight how student digital resources are designed and developed for encouraging real-time collaborative construction and sharing of inscriptions in a middle school (with 11-13 years old students), inquiry-based math classroom.

INSCRIPTIONS, INSCRIPTIONAL PRACTICES AND ITS IMPORTANCE IN COLLABORATIVE MATHEMATICS LEARNING

Inscriptions are powerful for collaborative learning because knowledge-construction takes place at the individual as well as the group level and students develop and use practices that emerge over time in a classroom setting (Medina & Suthers, 2013). To support students in the collaborative learning environments, Wu & Krajcik

(2006) found that embedding the use of inscriptions in the inquiry process, providing scaffolds to support inquiry, sequencing tasks, and the inquiry process, and engaging students iteratively in the inquiry process are critical for developing inscriptional practices. Students' individual inventions of inscriptions can be translated and integrated through social interactions into the conventions of the classroom community (Enyedy, 2005).

While inscriptions show promise for developing collaborative learning environments, challenges still remain. Sandoval & Millwood (2005) reported that students typically did not refer to specific features of inscriptions when making a claim, resulting in a limited or vague interpretation of the reference by others. Schnotz and Bannert (2003) observed that inscriptions are only effective when they are appropriate to the task. Bowen and Roth (2002) reported that learning with inscriptions is effective when students are "engaging in activities during which inscriptions are something 'everybody uses' to convince others of the utility and accuracy of their arguments" (p. 324). While most of the research on inscriptions for collaborative learning can be found in the science and technology literature, more research is needed in mathematics education (Cobb, 2002; Roth & McGinn, 1998).

THEORY OF INSCRIPTIONS

Roth and McGinn (1998) describe a theory of inscriptions around representing as a social practice. According to the theory (pp. 37-38), inscriptions have eight common characteristics:

- easily able to be sent and received,
- do not change when being sent or received,
- easily embedded into different contexts,
- easily modified,
- easily combined and superimposed with other inscriptions,
- reproduced at low economic, cognitive, and temporal cost,
- easily merged with geometry, and
- often translated into other inscriptions.

In mathematics, knowing and learning are "situated in social and intellectual communities of practice, and for their mathematical knowledge to be active and useful, individuals must learn to act and reason mathematically in the settings of their practice" (Greeno, 1988, p. 482). Thus, "to be a representationally literate individual means being able to participate in the practices of producing, comprehending, comparing, and critiquing inscriptions" (Roth & McGinn, 1998, p. 45).

RESEARCH GOALS AND METHODS

The research shared in this paper is part of a larger project that aims to study how the use of digital inscriptional resources can improve middle (11-13 years old) school students' mathematical understanding. Towards the goal of improving students' understanding, the larger project makes use of design research (Barab, 2014) to focus on iteratively developing and enacting a digital collaborative math environment.

According to Barab (2014) the goal of design based research is to "use the close study of learning as it unfolds within a naturalistic context that contains theoretically inspired innovations, usually that have passed through multiple iterations, to then develop new theories, artifacts, and practices that can be generalized to other schools and classrooms" (p. 151). In the larger research project, as part of the design research process, classroom data collection, data analysis, and informal and formal feedback from students and teachers using different methodologies inform subsequent iterations of development and enactment. Data sources include student and teacher interviews, student and teacher surveys, classroom video, computer screen recordings, student and teacher audio recordings, and copies of classroom artifacts. While examples of this development and research efforts that inform development are reported elsewhere (e.g., Edson, Kursav, & Sharma, 2018), the purpose of this paper is to draw on conjecture mapping (Sandoval, 2014) to show how theoretical perspectives, technology development, and implementation are interconnected. To this end, we will report on the mapping of three important distinctions necessary for testing conjectures in design research: (a) the design of the digital materials through the inscriptional theory perspective, (b) the development of the materials and its embodied features, and (c) a description of the learner's enacted experiences in the classroom. Evidence for these distinctions draws from different sources, including the theoretical and empirical research literature on inscriptional theories, user stories and feedback for iterative development of features, and classroom observations and opportunities afforded by the developed features. Thus, the contribution of this paper is to report, through the context of our design research efforts, on how the affordances of collaborative and dynamic inscriptions can be connected to the theory of inscriptions through digital technologies.

Over the years of the project, the research team worked with approximately 5 teachers and their students from several districts, each year that made use of the Connected Mathematics curriculum materials (Lappan, Phillips, Fey, & Friel, 2014). The Connected Mathematics is a problem-based middle school curriculum used in grades 6-8 in the United States and forms the curricular pillar of our work. The overarching curriculum and pedagogical ideas of this problem-based curriculum inform the design principles of the digital environment. The curriculum has existed in the print medium and we are currently in the process of studying the affordances and limitations of enacting the curriculum in the digital environment. In the curriculum, contextual tasks situations are used as mathematical problems and encourage some or all of the following features: (a) important and useful mathematics is embedded within the problem situation, (b) it stimulates both conceptual and procedural knowledge, (c) connects to and builds upon other core mathematical ideas, (d) warrants higher level thinking, problem-solving and reasoning skills (e.g., mathematical practices),(e) affords multiple entry points and access points into the problem, (f) ensures engagement for the learners and promotes rich mathematical discourse, and (g) creates opportunities for teachers to formatively assess the student learning (Lappan & Philips, 2009).

Figure 1 shows a screenshot of an individual student active in the digital platform developed as part of the design research study. In this digital platform, mathematics problems were (re)designed and presented in a new problem format. The intention behind the new problem-format is to further strengthen the emphasis on inquiry and exploration of mathematical ideas through rich problems, meaningful classroom discourse practices, and increased collaborative problem solving. In particular, the problems are now formatted within three components (a) the *Initial Challenge*, where students are introduced to the context of the problem situation.,(b)

Figure 1: Screenshot of the student working in the individual workspace on the digital platform.

What If…? where students are expected to unpack the embedded mathematics, and (c) *Now What Do You Know?* where students summarize their learning and makes the connection to their prior knowledge and may also highlight the relationship to related upcoming mathematical topics.

The digital platform supports real-time, synchronous collaboration among students, who upon logging into the specific problem are organized into groups of 2-4. Using the inscriptional features on their individual laptops, students can write text, draw figures (using the cursor), make tables, generate graphs, paste screenshots, upload photographs, and use stamps (pre-populated) on their individual workspace. The workplace of an individual student is connected to the workspaces of other students (in their group and also to others in the class). Students can also share their work with other groups by publishing it. Once published the work can also be accessed by students in other groups. In the digital platform, the students can drag and copy the inscriptions embedded into any other workspace into their individual workspace. The other workspace could be - the problem workspace, other students' workspace, and also the teacher's workspace. The *Learning Log* provides a distinct space in the digital platform for students to curate, collect, revise, combine, and revisit inscriptions. The Learning Log is intended as a place for students to record overarching ideas that span across problems, units and even grades. At the teacher's end , the digital platform offers features, such as, (a) assigning individuals to specific groups, (b) accessing student's individual and group workspaces, (b) creating customizable "just in time" prompts that can be directed at individual students, groups, or the class, and (c) presenting selected student's work along with added annotations and also publishing it (and hence sharing it with the class) during whole-class discussions. While most of the inscriptional tools and the collaborative features are common and remain constant across problems, the problem space is customized for each of the problem with specific inscriptional tools (including mathematics-specific tools). The inscriptional resources are hence- carefully selected keeping in mind the mathematical learning goals contributing to creations of inscriptions that relate to the embedded mathematics into the problem. The resulting set of inscriptional and collaboration features in the digital platform hence accord specific mathematical problem-solving capabilities and distinguishes it from other generic collaboration platforms that might be found in other content areas.

The above description of the digital platform makes it easy to see how many of the eight characteristics of inscriptions (like easy transferability, modifiability, remaining unchanged, reproducibility, superimposing and others) identified by Roth and McGinn (1998) are feasible in the context of this digital platform. It is interesting to note that with the innovations introduced in the digital platform, new inscriptional characteristics and affordances have emerged. In the following section, we discuss examples of intended and actual use of the digital platform, by the students, for constructing and sharing inscriptions.

CONSTRUCTING AND SHARING INSCRIPTIONS USING THE REAL-TIME, COLLABORATIVE AND DYNAMIC DIGITAL ENVIRONMENT

As detailed above, the collaborative digital platform forms the design innovation for constructing and sharing inscriptions. Figure 2 shows the screenshot of the laptop screen of the same student as before. The individual screens of the other three group members are also visible to the student. The students are working on a mathematics problem from the seventh-grade unit, *Stretching and Shrinking: Understanding Similarity*. Problem 2.2 Hats Off to the Wumps: Changing a Figure's Size and Location. The overall learning objective of the problem is to help students use scale factors and ratios to describe relationships among the side lengths, perimeters, and areas of similar figures. More specifically students see how some similarity transformations, through changes in the *x*- and/or *y*-coordinate, move the figure (hat) and /or change the size around but preserve its similarity.

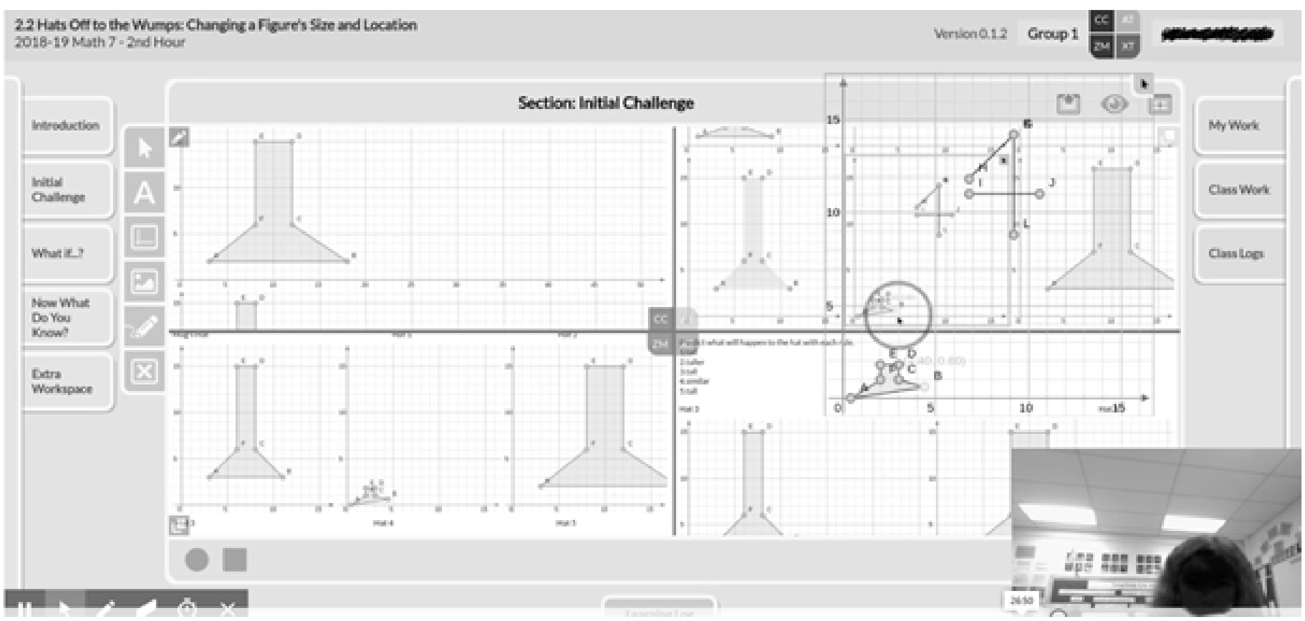

Figure 2: Screenshot of a student collaborating with other group members

We use the context of the problem above to highlight specific examples how students from our research used the digital platform to construct and share inscriptions. Collectively, these examples of the available features and the actual enactment indicate the emerging affordances of inscriptions and highlight the potential to strengthen inscriptional practices using innovative use of technology. To this end, we primarily draw on the data sources of classroom video and computer screen recordings to report on classroom observations that relate to the student use of the digital resources. Other data sources are used to affirm or refute (and subsequently modify) the classroom observations reported in this paper.

Students use of digital platform to construct automatic and dynamic inscriptions

In the digital platform, classroom observations revealed that students can create new inscriptions that build on existing work, which are automatically generated and are dynamically linked across multiple inscriptions. In the above example, students can drag inscriptions (for e.g. the diagram of the hat(s), table containing the transformation rules and coordinates) from any problem component or workspace into their individual workspace without needing to recreate them. The red circle in Figure 2 is the cursor of the student who is trying to drag and embed an inscription from another student's workspace into their individual workspace. Classroom observations revealed that the digital platform not only allows students to collectively populate the coordinates in the table corresponding to the given rules, but it also automatically generates the corresponding figure on the coordinate grid. Classroom observations revealed that the platform also allows the students to hide or make visible any hat and also to move the hats on the coordinate grid as they compare the hats for similarity. The physical movement and laying of a hat over the other hats, opens up additional opportunities for determining similarity (specifically angles). Importantly, as the students attempt moving the hats, the corresponding changes in the rules and coordinates are reflected in the table in real time due to the linked nature of the table and the graphing tool. It was also observed that the instant and dynamically linked nature of the inscriptions enabled the students to test their own rules and map the corresponding movement and / or changes in the hats and vice-versa.

Students use of digital platform to collaboratively share inscriptions

Classroom observations revealed that the digital platform allows students to generate, share, and access inscriptions synchronously and in real-time. For example, in the figure above, by giving permission, any student in the group can allow the other group members to see their individual work in real-time. Also, classroom observations revealed that the publish feature allows the student to post their work which is then accessible to the whole class. Students in a group can work together on a single workspace where each one of them can work on the same (or different) components. As the students have real-time access to each other inscription, the student can compare and contrast the alternative strategies, ask for clarification, revise their own strategies to use alternative/multiple ideas, and practice the metacognitive skill of evaluating and choosing the most appropriate solution strategy. Classroom observations further revealed that the platform also offers easy accessibility, retrievability and reusability of digital inscriptions, and the ability to organize it within the learning log space. As the class reviews and discusses the concepts related to the mathematical goal, specifically using the *Now What Do You Know* prompt, it was observed that the digital platform allows learners to readily embed inscriptions from curriculum materials, problem workspaces, the workspaces of classmates or the teacher, or prior learning log entries into their learning log. In the example above, students can combine and/or edit the inscriptions to reflect their evolving mathematical understanding of similarity, making deeper connections to other concepts and procedures including those from previous problems.

These novel affordances of constructing and sharing inscriptions using the digital platform have implications for the inscriptional practices and mathematical proficiency.

DISCUSSION

The research literature shows that student capacity to represent knowledge and make sense of their inscriptions is essential for conceptual understanding within mathematics (Medina & Suthers, 2013; Cobb, 2002). However, capturing inscriptional construction practices is messy and complicated (Roth & McGinn, 1998), especially in the context of collaborative small group classroom settings. Given the advances in digital technologies, we have new opportunities to utilize inscriptional practices that are "in-the-moment." Many of the affordances related to the construction of inscriptions detailed above (like instant dragging and copying, constructing collaboratively and in real-time, dynamic interlinking of multiple inscriptions, temporally extending the inscription construction, easy retrievability and combining) are difficult to replicate not only in the paper-pencil context but also through the use of traditional technology tools. The emerging affordances through the use of innovative technology can enable learners to focus their cognitive effort on the important inscriptional competence rather than on the procedural aspects of inscriptions. Thus, these affordances can contribute in helping students make coherent connections among mathematical ideas that otherwise may appear arbitrary and disconnected.

diSessa (2004) foregrounds the importance of "metarepresentational" competencies that go beyond the production and interpretation of inscriptions. These include the competencies to invent or design new inscriptions; to critique and compare the adequacy of different inscriptions; to understand purposes, contexts and the ways in which inscriptions work; explain the inscriptions itself and the connections across inscriptions; and to engage with new inscriptions (Kindfield & Gabella,2010). Using the affordances of collaboratively sharing inscriptions and having real-time access to one another's problem-solving strategies can promote "metarepresentational" competencies and facilitate collaborative sense making. By making the process of inscriptional construction and sensemaking publicly shared and negotiated among students, the affordances of the digital platform can strengthen the social dimension of the inscriptional practices.

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