Design Math: Middle-School Youth Making Math by Building Yurts

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Abstract: While Project-Based Learning (PBL) has been shown to be an effective approach to learning, teaching math through PBL has long been challenging for practitioners. To explore new ways to engage youth and complement math learning in the classroom, researchers and middle school teachers collaborated to implement a year-long PBL course, "Design Math." This course supported math learning through design and textile-based crafting projects by leveraging embodiment and tangible manipulatives. Students built life-size and scale-model yurts (i.e., tents) while adhering to a set of design constraints. Preliminary findings suggest that project-based approaches in math learning have the potential to promote and sustain student engagement, broaden participation in mathematical thinking, and afford deeper conceptual understanding of the mathematical concepts of measurement and geometry.

Keywords: Project-based math learning, geometry, middle-school math, Constructionism

Introduction

In 2016, the U.S. Bureau of Labor Statistics projected that the strongest job growth in the next decade will be in the areas of "operations research analysts, statisticians, actuaries, and other mathematics-oriented jobs," which are projected to grow by 28% (compared with just 12.5% for computer and information technology) (DeSilver, 2016). Giving the growing employment trends for math-oriented jobs, it is startling to see that only 33% of eighth-grade students are at or above their math proficient level (U.S. Department of Education, 2015). That is, while math is increasingly important for job-seekers in the United States, those who are educated in the U.S. are less qualified to fill these positions. But more than exclusively making a "market economy" argument of supply versus demand, the poor math performance trend of these students is an indicator of insufficient preparation in prior grades and for future academic years, especially if they will be pursuing STEM careers.

For more than two decades, Project-Based Learning (PBL; Blumenfeld et al., 1991; Krajcik & Shin, 2014) has been an effective pedagogical approach to developing problem solving skills, deeper conceptual understanding, and increasing engagement. However, studies of *project-based math* initiatives are outnumbered by studies of project-based learning in science and social studies (Condliffe et al., 2017). In order to contribute to the understanding of the effectiveness of project-based learning for math content and practices, we partnered with a public charter school. This unique setting has integrated PBL across its entire educational ecosystem (i.e., teachers, students, curriculum, culture) for over eight years, but not as consistently every year for mathematics. To address this need, we developed a Research-Practice Partnership with teachers and administrators for grades 7-8 for the co-creation and implementation of a new PBL math curriculum, Design Math (DM).

DM is a set of collaborative PBL activities for the learning of middle-school geometry through designing, modeling, and sewing in two projects: a scale model and a full-size fabric yurt (i.e., tent). DM is designed to address a number of Indiana State's middle-school geometry math standards, including (1) 2D-3D nets, (2) protractor use, (3) area and volume calculation, (4) angle types (e.g., acute, obtuse), (5) congruence, and (6) transformations. In our research, we sought to discover whether students in grades 7-8 demonstrate mathematical proficiency as defined by the National Research Council (NRC) through their involvement in DM, as well as to uncover the extent to which this project-based math learning initiative affords conceptual understanding of geometry and measurement, increases and sustain student engagement, and promotes problem solving skills.

Background

Since the 1990s, major reforms in mathematics education have resulted in periodic Math Standards (e.g., National Council of Teachers of Mathematics, 2000) which guide all state educational systems with one common understanding of mathematical proficiency. The National Research Council (2002, 2005) defined mathematical proficiency as five interdependent strands: **conceptual understanding**, **procedural fluency** (computing), **strategic competence** (applying), **adaptive reasoning**, and **productive disposition** (engaging).

When math is believed to be just rules and procedures, one is putting a lot of emphasis on the computing strand that produces a weak level of math proficiency. But if pedagogical approaches include all strands, then they will produce strong sense making necessary for successful problem solving (NRC, 2005). Research shows that PBL usually involves real-world contexts, supporting and promoting deeper understanding, and sustained engagement (Epstein et al., 2010). PBL is also collaborative and cognitively engaging, with multiple sources of support as students apply their knowledge and understanding of concepts (Blumenfeld et al., 1991). Thus, we believe that PBL aligns with the goals of mathematical proficiency.

However, project-based math can be challenging. Working outside of "traditional" textbooks and curriculum can be seen as risky for teachers given the high-stakes nature of math performance in today's public school context. Thus, teachers are rightly concerned about students performing adequately on both state and district standardized tests (Huberman et al., 2014). Other challenges are that PBL takes more time to prepare and implement than more traditional approaches; it needs careful preparation to provide scaffolds and to be able to implement during limited class periods. PBL activities also introduce classroom management skills different from those of the traditional classroom, such as providing constant feedback, giving more time for reflection, and facilitating small-group collaboration, among others (Darling-Hammond et al, 2008).

Though PBL has not traditionally focused on including the creation of tangible manipulatives in the projects, the production of personally meaningful artifacts (i.e., "objects-to-think-with") can support the learning of underlying concepts that are inherent in the materials used during construction (Papert, 1980). According to constructionist theory, learning happens best when learners build knowledge structures in context through designing publicly shareable artifacts and also ongoing reflection (Papert & Harel, 1991). We take this as the theoretical basis for the hands-on, tangible design of DM.

Methods

Design Math took place in a public not-for-profit charter school with about 270 students; about 36% were eligible for free or reduced lunch. DM took place 1-2 times per week in one-hour sessions for one school year. The participants were 72 students (25 girls and 47 boys), mostly from grades 7 and 8, and a few math-advanced students from grades 5 and 6. The three teachers in this classroom were the primary drivers of the curriculum development, receiving occasional suggestions from researchers.

Though we administered a variety of assessments throughout the year, including a final survey to learn about student perceptions of the benefits of DM and final semi-structured interviews with focal students, in this short paper we focus on the video recordings of the construction of the life-size yurt. In the first half of the school year, the project was to create a full-size yurt large enough to fit eight students and be able to withstand outdoor conditions of a cold fall night (see Figure 1). They were provided with a prompt (i.e., build a 5-side yurt using wood, canvas, and other provided materials and tools) and worked in groups to accomplish the goal.

Figure 1. "Yurt Day" at the farm. Middle school students building their yurts from their blueprints.

After two 1-hour planning sessions in the classroom, the class took a one-night camping trip to a farm where the life-size yurts were put to the test in a real-world context. The time to complete their project was unconstrained, except they had to have a final structure to spend the night in. We video recorded the building process of three groups, for eight hours each. In the second half of the school year for the second project, students were instructed to build a scaled-down model of a yurt of their choice with a short concept statement, scaled floor plan, orthographic drawings (top, front, back, and sides), 3D perspective images, and optional, scaled furniture.

Findings

The data we present here (see Table 1) comes from Sam (8th grade), Rob (6th), Todd (8th), Peter (7th), and Gabe (7th). This piece comes from a video recorded, semi-structured interview inside the yurt they built during the experience on the farm. This group talked about their understanding of specific geometric concepts when one of the authors asked them to imagine they were substitute math instructors of 6th grade students. Then he asked: *"Do you think this [DM] project would teach them [6th graders] geometry? Yes or no? And how would it teach them better?... Is it helpful? Not helpful?"*

Table 1: Excerpt of one interview transcription with one of the focal groups during the trip to the farm

Sam:	I think it will definitely help them with geometry. Because, like, for each side we had to measure like the angles and get the right shapes and why not...like figuring out like building architecture...
Rob:	Yeah I think 'cause the main thing I learned was the surface area. I've never heard that like um
Interviewer:	Where's the surface area here (pointing inside the yurt)?
Peter:	Outside. Everywhere.
Todd:	Anywhere. Anywhere there's stuff.
Rob:	What was it? (looking at Todd as if expecting an answer). It was like 140 square feet.
Gabe:	It was 110 square feet. Well, it was supposed to be (boys chuckle).
Todd:	We got it pretty exact…
Peter:	So I think this is really a hands-on thing and I used to think that's a better than there's like a paper (clapping hands as if holding a paper to show the flat surface of it) that says "what's um the surface area?" It's shaped like it's better to like, you, to look at it from different perspectives. And um if it's a challenge you'll think about it more and I think that it would just kind of burn it into your brain like...I'll remember this.
Gabe:	Um, yeah I also think this is like a really good thing, 'cause a lot of stuff I kind of already knew already...there's no reason for me to know it... it was just kind of another... thing of math that, I ...learned from my teacher that I would never use but...you have to use stuff like...finding how to make a pentagon, like finding the angles, measuring all the stuff, like finding the hypotenuses, Pythagorean Theorem, all that stuff, we really have to actually use it, 'cause we have to sleep in these. Like we have to build this and then if we, like if we hadn't finished it we would still have to sleep here. So it really gives us like good incentive and, like, like, real world, I don't know, connections, to like all that math that you learn in school that you don't think you need.
Todd:	I have to, like, add on to that, like I don't think I, I personally, I don't think I learned a new, entirely new like, a concept, but putting them into real life, other than, um, just knowing them it is an entirely different level of learning math.

This exchange demonstrates examples of **understanding, applying, reasoning,** and **engaging** (i.e., math proficiency). Rob expresses **understanding** when he says, "the main thing I learned was the surface area." Peter alludes to easier future recall due to deeper **understanding** when he says, "I think that [the challenge] it would just kind of burn it into your brain like...I'll remember this." Gabe demonstrates **application** of the math when he says, "you have to use stuff like...finding how to make a pentagon, like finding the angles..." Peter shows **reasoning** when he says "it's better to...look at it [hands-on project] from different perspectives." Gabe also shows an example of **application** and **engagement** when he says, "[the project] really gives us like good incentive and, like, like, real world, I don't know, connections, to like all that math that you learn in school that you don't think you need."

Discussion and implications

This short interview extract provides evidence of math proficiency we are uncovering through the analysis of our data corpus. DM, as a project-based math learning initiative afforded conceptual understanding of geometry, increased and sustained student engagement, and promoted problem solving skills. Anecdotal data from parents and graduation speeches from 8th grade students also shared how the "yurt project" (DM) was a favorite project.

Standardized tests may need to be adapted to place greater emphasis on other forms of math proficiency beyond conceptual understanding and procedural fluency (computing) (NRC, 2005; Darling-Hammond, et al., 2008). For instance, math education researchers Boaler and Staples (2008) found that "unfamiliar terms and culturally biased contexts" of a state standardized test may have contributed to its "inability...to capture the mathematical understanding" of their research participants involved in a project-based math curriculum (625). When in fact, their participants successfully demonstrated mathematical understanding in different assessments administered by the researchers. If more schools continue to adopt PBL in math classrooms, high-stake State assessments may need to be optimized to adequately measure mathematical proficiency for all five interdependent strands (i.e., understanding, computing, applying, reasoning, and engaging).

In an upcoming paper, we expect to share our findings that could contribute to design principles of these types of PBL math initiatives for math proficiency, particularly with the infusion of hands-on projects involving textile-based materials to help students create their personal manipulatives ("objects-to-think-with"). We would also pinpoint design and implementation challenges of DM to identify areas of research to spread the benefits of PBL for math to help students be prepared in an increasingly technical and math-based world.

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