Design Math: A Design and Project-based Effort to Learn Geometry in Middle School through Fabric-Based Yurts

Tarrence Banks, PhD
The Project School
Bloomington, Indiana
theprojectschool.org
bankst54
@theprojectschool.org

Scott Wallace
The Project School
Bloomington, Indiana
theprojectschool.org
swallace
@theprojectschool.org

John Searcy
The Project School
Bloomington, Indiana
theprojectschool.org
jsearcy
@theprojectschool.org

Mishael Sedas
Indiana University
Bloomington, Indiana
creativitylabs.com
rmsedas
@indiana.edu

Kylie Peppler, PhD
Indiana University
Bloomington, Indiana
creativitylabs.com
kpeppler
@indiana.edu

ABSTRACT

The lack of engagement and real-world applications and contexts in regular mathematics classrooms contribute to the potential avoidance of mathematics. *Design Math (DM)* was a set of yearlong collaborative project-based learning activities to support the learning of middle-school geometry curriculum through design, modeling, and sewing of fabric-based yurts (tents), one full size and one scaled model. We incorporated state standards, real-world contexts, and design-inspired curriculum into *DM* that generated extreme interest and enthusiasm from students, parents, and community members. Based on the success of this project and the pleadings of students and families, we will have *DM* for a second time this coming school year. The Project School in Bloomington, Indiana, is a teacher-created K-8 public not-for-profit charter school. Classrooms are multi-aged and team-taught with a strong commitment to arts infusion.

Keywords

Geometry; Math; Yurt; Shelter Design; Scale; Sewing; Project-Based Learning; Design Inspired; Design Process

1. INTRODUCTION

Finding effective ways to structure project-based pedagogical activities for math has proven challenging, even in a project-based environment. Working outside of "traditional" textbooks and curriculum can be risky for teachers given the high-stakes nature of math performance in today's public school context. Consequently, we propose a new approach to fully leverage design and project-based approaches to create new ways to promote and sustain student engagement, broaden their participation in mathematical thinking, and afford deeper conceptual understanding of geometry through fabric-based physical manipulatives. This paper focuses on the design and development of the Design Math (DM) model at The Project School.

2. DESCRIPTION

2.1 Setting

The Project School (TPS) is a public not-for-profit charter school located in the university town of Bloomington, Indiana. Being a university town, TPS students are a cross-section of the surrounding communities, but without a considerable number of international students or English Language Learners. TPS has 277 students, kindergarten through grade eight from Bloomington, Monroe County, and surrounding communities. In Indiana, public charter schools must enroll students using a lottery system, so no admission criteria exist other than residency within the state. TPS has a 95%+ annual enrollment retention rate, 36% of the students are eligible for free or reduced lunch, and 22% of them have Individual Education Plans (IEPs) to support special learning needs; at the middle school level, almost 40% had IEPs in this school year during DM.

2.2 Educational experience

At TPS, Mathematics is a standalone course, and although we strive to come up with hands-on and authentic experiences for the classroom, it feels very different from the rest of the academic day. The teaching of other subjects is done through project-based methods that allow students to become problem solvers for issues that impact real people and places. In a previous year, we had a successful design-inspired yearlong project on aquaponic systems, so this school year, Scott and Tarrey decided to put what they learned into practice and attempt a design-inspired yearlong math project. Seventy-two students (25 girls and 47 boys) mostly from grades 7-8 participated in *Design Math (DM)* once or twice a week for one hour. DM is a set of project-based learning activities to support the learning of middle-school geometry curriculum through design, modeling, and sewing of fabric-based *yurts* (tents), one full size and one scaled model.

DESIGN. We looked at *design* as a productive approach because of the following characteristics. Design is an iterative activity that usually begins with a problem needing to be solved. A designer starts understanding and exploring the problem by conducting research with the main stakeholders and through prior knowledge recorded in secondary sources like journals, or any historical source. Then, he or she gets involved in ideation through sketching, looking for solutions or designs. These designs are critiqued and tested by others. Learning content through design (e.g., fractions and science concepts) has been explored in the past (e.g., Harel, 1988/1991; Kafai, 1995/1996; Kolodner et al., 2003) and among many other benefits, this approach allows for sustained engagement and for students to take control of their learning.

WHY YURTS? Tarrey and Mishael were both already engaged with a research project funded by the National Science Foundation (NSF) entitled "Re-Crafting Mathematics Education: Designing Tangible Manipulatives Rooted in Traditional Female Crafts" (RCM). The goal of RCM is to better understand how traditional female crafting practices can make far-reaching improvements in a range of learning outcomes in STEM education. As a RCM fellow, Tarrey had been working on developing a set of physical manipulatives and activities to teach math through an embodied, design-inspired approach to learning. In previous semesters, Tarrey had designed and implemented several iterations of a 3-4 week math project focused on tent and shelter design including pattern making and sewing skills. In the spirit of RCM's focus on traditional female textile crafts, students' designs were each required to use fabric as their primary material and incorporate either hand or machine sewing. As a teaching team, we reflected on this previous work and the idea of the *yurt* as an architectural concept surfaced with the idea of engaging in this project for the entire year.

PLANNING AND BRAINSTORMING. In our classroom, we often speak of "*liberating constraints*" (Davis, Sumara, & Luce-Kapler, 2000, 87) in the context of Project-Based Learning (PBL) as providing just the right level of organization and structure to focus students on the work while simultaneously planning for intentional flexibility to engage an array of abilities, interests, and diverse student perspectives. While PBL (e.g., Boss & Kraus, 2007) is often touted as being completely open-ended, we have found that constraining a project provides multiple benefits to student outcomes. In a previous class project, we worked with an architect who told us that he can be most creative when he is given clear constraints (e.g., Stokes, 2005). We have witnessed this, time and time again, and it was also true in DM. Rather than allowing students to create *any* type of shelter, we focused on yurts. We also required all students to use the same materials to make the full-size yurts and the scale models. In removing some of the open-endedness of a project, students were actually able to be more creative and found the project more enjoyable. It is always interesting to see all the variations that students create within the constraints.

Regarding the math content we were going to include in DM, we began to do some preliminary research on yurts and decided it was not only another iteration of our RCM work, but also a design-based project that provided opportunities as middle-school teachers to cover a wide variety of geometrical concepts. We identified Indiana's 7th and 8th grade geometry math standards (e.g., scale) and explicitly committed to cover most of them in our DM periods and not in our typical math classes during the rest of the week.

PHASE 1-EXPLICIT CONTENT/STANDARDS-BASED MATH LESSONS. In August of 2016, we began DM by telling students that we would be learning about, designing, and constructing *yurts* as a class during the school year, and that in order to do that, they would need to learn some specific math concepts and skills that they could put to use. So we began a series of fairly typical lessons covering geometric standards like 2D-3D nets, protractor use, area and volume calculation, angle types (e.g. acute, obtuse), congruence, and transformations. After becoming proficient with the basic concepts, students completed a series of "Design Challenges"—simple tasks to help with deeper understanding of the learned geometric concepts so far *(e.g., label the acute angles in the net of a square pyramid)*. During our DM class periods, students worked in teams to put in practice what they were learning (Figure 1) in preparation for the full-scale yurt build day.

Figure 1. Figuring out the math. From left to right, boys check the area of a yurt footprint, girls calculate the hypotenuse for roof triangular panels with a tape measure, and two boys use trigonometry to also calculate the hypotenuse for their roof panels.

PHASE 2-FULL-SCALE YURT BUILD DAY. We decided to have a hands-on experience in a farm for the students to explore yurt design and be engaged in an authentic way. Students were challenged to build and sleep for the night in a yurt-like shelter they designed themselves while utilizing the geometry and yurt design principles they had been exposed to in class. After a couple of DM periods dedicated to planning and design, in early November student teams built their full-size yurt-like tents. As designers, we wanted our students to think about who and what they are designing for, so the experience was framed around empathizing with people like refugees who have to live this experience daily. We gave each team the same kind of materials in the same quantities. Materials included: large canvas painting tarps, plastic tarps, wooden stakes, staples, duct tape, rope, twine, and plastic sheeting (Figure 2). We chose to utilize a simple yurt design plan called the Hexayurt. Hexayurts are designed to be inexpensive, easy to build, and completely open source, and constructed from materials that can be found locally (http://hexayurt.com). Working on a full-size yurt presented challenges that do not exist for students working on a scale-model tent. For example, hot glue guns were later used extensively for the small model, whereas for the life-size yurt, students had to learn how to join together fabric and wood or both in ways that hot glue just cannot do!

Figure 2. "Yurt Day" at the farm. Middle school students building their yurts from their blueprints.

PHASE 3 - SCALE YURT DESIGN CHALLENGE. In framing the requirements for the design challenge during the second half of DM, we again followed the concept of 'liberating constraints'. The design challenge consisted of building a model of a yurt to scale and providing the following deliverables: a 200-word concept statement, ¼-inch scale floor plan drawing, orthographic (elevation) drawings for each side of the yurt, and 3D isometric drawings from multiple views. We used an architecture project (undergraduate level from Ball State University) as an example. To provide an extra level of challenge for students besides building the scale model, we added the following optional and ‘above and beyond’ deliverables: 3D floor plan, concept statement for interior elements, scale models of sustainability features, interior elements (furniture, utilities, etc.), and advertising materials. We believe these requirements (constraints) created a good degree of flexibility and guidance to set the students up for success and maintain a high level of problem solving and engagement.

TOOLS, TECHNOLOGY, AND MATERIALS. The embedded makerspace in our classroom is fully integrated into our daily project-based work, and this project was no exception. Except for sewing tools, we did not require students to use any particular tool or technology. Some teams utilized digital design tools like Adobe Illustrator and/or InkScape to design components of their yurts, and the laser cutter to fabricate them. Other teams used a less technology-heavy process, hand drawing their components of the structure and using eXacto knives to do the final fabrication. Students also used the 3D printer and programs like Tinkercad to design and fabricate components, or interior elements such as furniture. Because this project focused on exploring traditional crafting in math, we intentionally incorporated textiles and sewing into as many components of the project as we could. Each team was required to utilize the reclaimed canvas tarp fabric from Yurt Build Day previously described into their designs and final models. Each team designated at least one team member to become the ‘sewing expert’. Parents and university volunteers came every week to the classroom and worked with students on basic hand and machine sewing techniques (Figure 3).

CONSTRUCTION DAYS. Lastly, the final few weeks of the school year were a frenzy. Students were working in teams and a few individually were measuring, cutting, gluing, and sewing with intention! (see online video link below). We provided support wherever it was required, whether teams needed help to use the laser cutter, or needed a further challenge when almost finished, to extend their projects to the next level. As teachers, it is a big challenge to be okay with groups of students working and doing very little teacher-focused or large-group direct instruction. But our desire for control would be no excuse for taking away the last few sessions of yurt-building, when students were most excited and engaged.

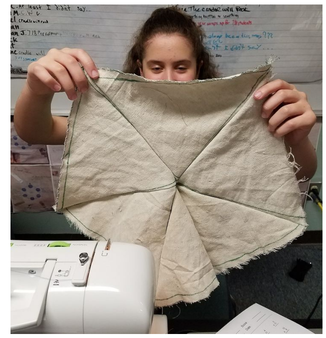

Figure 3. Girl shows sewn yurt roof

3. CONCLUSION

3.1 Results

Without a doubt, students found DM, or as they called it, “the yurt project,” to be a highlight of their year. In the end-of-the-year graduation speeches, eighth graders talked about the “yurt project” more often than any of the other projects from the year, yet it was the only project that was not fully integrated into other curriculum and teams only met once a week to complete it. Why then was it so popular? This PBL/Design project was cognitively engaging, collaborative, and afforded multiple sources of support for the students (e.g. teachers, other students, volunteers, online resources) while they applied their knowledge and understanding (Blumenfeld et al., 1991) of geometry and measurement. Also many students enjoyed making scale model furnishings - not a requirement, but one that allowed them to explore their creativity, new technologies, and processes. The level of detail in many models was impressive (Figure 4). At the end of the school year we administered a survey to find out the students’ likes, dislikes, and suggestions about improving DM. Table 1 includes optimistic (for us) verbatim responses from three students about DM’s approach to math learning.

Table 1. Verbatim responses to one of the questions of our final survey about Design Math activities

Did you like working on hands-on projects with [the provided] materials to learn or better understand math? Why? [or] why not?		
“Yes I think it's really different using math this way and you can learn a lot because there are a whole other set of skills that have to go into it. It's different because on paper if you get a question wrong it's not a big deal you can erase it and try again. If your [sic] constructing something it's easier to see where you went wrong but it can be harder to solve your mistake. When you're working on a project like the yurt project you have to think through all the pieces and double check or else it could hurt your whole project. It helps to understand the math better because you can really see how and why things work the way they do.” **Girl, 6th grade in Pre-Algebra**	*“Yes because it clicked in my head more so than being told this is what i [sic] can do with it, i [sic] was told how i [sic] could use the mathematical skill or how it would benefit me to know it but never actually got to use it in a real life situation.”* **Boy, 8th grade in Pre-Algebra**	*“I really loved this project, it made me do math to build somthing [sic] and I don't dislike math as much now. We need to do something similar next year but we should do it more often.”* **Girl, 7th grade in 7th Math**

Figure 4. Examples of scale yurts with remarkable details displayed at the school’s Museum of Authentic Work (MAW).

One thing we would have done differently. We would have modeled the actual yurts kids would build in scale before building the full-sized yurts. Due to the time constraints with our grant and the cold Indiana winter, we had to get kids building the full-sized yurts before building a scale model. It would have been nice to have students compare their scale model yurt to the life-size yurt in real time, and compare and contrast the different construction techniques used for each yurt. Though doing the large-scale yurt early on in the project did generate a lot of excitement from the students we drew upon as we were teaching "traditional" lessons to get students prepared to build the scale models. These two verbatim survey responses about the most rewarding moments of DM and what parts students recommended to use again in the following school year represent the whole class's sentiment about the large-scale yurt experience in the outdoors: *"The yurt project by far was the most rewarding and happy moment. Going to [the] farm and building a yurt that my team and I would sleep in was extremely rewarding. The hard work of planning measurements and angles at school payed [sic] off and presented the reality of math"* Boy, 8th grade. *"When we made the yurts at [the] farm because it was a community building activity but also you built something you were going to sleep on so it mattered if there where wholes [sic] or if the door was messed up because you were sleeping in it…"* Girl, 7th grade.

At the end of every school year, The Project School celebrates the work of the school in a Museum of Authentic Work (MAW). The school transforms into a museum, where students act as docents and tour family, friends, peers, and community members through the displays that document the learning that occurred that year. The yurts were a highlight for both students and guests on the tour. Having the scale models up in the hallways and classroom for observation prompted a variety of conversations with adults and kids connected to the yurt builder(s). In fact, in the weeks after the MAW, we fielded multiple emails from people asking us for more information about the project, and even one seeking the original yurts we built and slept in for an upcoming festival!

3.2 Broader Value

The RCM research team is currently analyzing the collected data of DM (e.g., survey responses, interviews of focal students, pre/post attitude tests towards math, video clips), for evidence about the pedagogical value of DM activities. Preliminary analyses align with the theoretical work of Papert and Harel (1991) where the learner "felicitously" builds knowledge structures in context while being "consciously engaged in constructing a public entity" or as Papert (1980) said, "objects-to-think-with". From the perspective of math education researchers, the preliminary findings agree with the work of Lesh, Post, and Behr (1987) on the benefits of being able to "be flexible" and "switch" among conceptual representations (e.g. drawings, math symbols, physical manipulatives such as the yurts) in successful math learning and problem solving performance.

Although project-based activities are not uncommon, DM and other projects we have done previously have taught us some things. Firstly, math and PBL can coexist. Because the implementation of PBL tends to deemphasize rote memorization and recall, it often has received negative responses in the math classroom. We set out to challenge the notion that PBL and math cannot exist in harmony. Student response data from our final survey do show that students much preferred the yurt project math sessions to the other, more traditional, math classes throughout the week. Another lesson learned was that 'Math PBL' allowed multi-age and multi-ability students in projects as young as 5th grade (in 7th grade math class) and as advanced as Algebra II to work together on the same project. There were many opportunities for students with more advanced mathematical skills to teach their teammates an application for something they'd learned. For example, when measuring the panels to be sewn for the pitched roof, some groups needed trigonometric ratios. Many groups had students who were enrolled in Geometry or Algebra II, so those students recognized the need right away and helped make the calculations for the panels.

As a teaching team, we are committed to the philosophy that if we want students to see themselves as professionals (or potential professionals), the students must have the opportunity to use the tools that professionals use. For this reason, our classroom is filled with physical tools, many from the teachers' homes. Chopsaws, jigsaws, mitre boxes, drills, sewing machines, and chisels are used by any student that wants to learn how to use them. More sophisticated digital tools like the Adobe Suite and other specific softwares, while more difficult to acquire, are important for us to aim to use as well. This is an area in which we continue to stretch ourselves.

Right away we learned that students were taking *Design Math* home with them. Parents reported students working on their sewing machines or raiding the family's sewing kit for needles and thread. At Christmas time, one student modified the family tradition of building gingerbread houses by making a gingerbread yurt! *Design Math* served as an anchor point for conversations between families and teachers about what was happening at school both academically and emotionally, not just about math.

3.3 Relevance to Theme

For the past five years, our teaching team and partners from Indiana University have engaged in deep inquiry around how to infuse the Maker Movement's spirit and practices in alongside our pedagogical approach. That is, we bring in ideas and concepts of the design process and design thinking, project-problem-placed-based learning, sustainability, and social justice and equity to create an environment that manifests in dynamic learning experiences that are multidisciplinary and wildly engaging. With a great deal of the maker-inspired experiences taking place outside of the mainstream public school setting, we are deeply concerned with bringing the movement back into the schoolhouse. Our teaching team, working alongside our university partners, have explored what a fully integrated makerspace can look like in terms of the architecture of our curriculum. Our utilization of various iterations of the design process has become the unifying concept around which we build our curriculum. DM is an example of how we are working collaboratively to create an ecosystem that allows for the full and effective integration of design thinking and makerspace tools, technology and materials to permeate educational spaces that have proven difficult for even the most experienced and confident teachers.

4. BIOS

Scott Wallace ***(panel member)*** is a lead teacher in the 7th and 8th grade classroom with a passion for math and science. He is a 2017 recipient of the Lilly Foundation Teacher Creativity Fellowship, which allowed him to begin beekeeping on his small wannabe homestead.

Dr. Tarrence Banks is one of the founders of The Project School where he serves as a lead teacher on the 7th and 8th grade team. He has two decades of experience in schools and degrees in elementary education, educational leadership, and sustainability education.

John Searcy is a lead teacher at The Project School. His math teaching was documented and used for training other Indiana teachers via the Southeastern IN I-STEM Project at IUPUI-Columbus.

Mishael Sedas is a Ph.D. student in Learning Sciences at Indiana University under Dr. Kylie Peppler. He is interested in using *design* to foster and support interest-driven learning of STEAM content for non-dominant and low-income populations (mishaelsedas.com).

Dr. Kylie Peppler is an Associate Professor of Learning Sciences and engages in research that focuses on the intersection of arts, computational technologies & interest-driven learning (kpeppler.com). She is the Director of the Creativity Labs at Indiana University.

5. REFERENCES

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. Educational psychologist, 26(3-4), 369-398.

Boss, S., & Krauss, J. (2007). Reinventing project-based learning: Your field guide to real-world projects in the digital age. Eugene, OR: International Society for Technology in Education.

Davis, B., Sumara, D. J., & Luce-Kapler, R. (2000). Engaging minds: Changing teaching in complex times. Routledge.

Harel, I. (1988). Software design for learning: Children's construction of meaning for fractions and logo programming. MIT

Harel, I. (1991). Children designers. Norwood, NJ: Ablex

Harel, I., & Papert, S. (1990). Software design as a learning environment. Interactive Learning Environment, 1(1), 1-32.

Kafai, Y. B. (1995). Minds in play: Computer game design as a context for children's learning: Routledge.

Kafai, Y. B. (1996). Learning design by making games. In Kafai, Y. B., & Resnick, M. (Eds). Constructionism in practice: Designing, thinking, and learning in a digital world: Routledge.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., ... & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by designTM into practice. The journal of the learning sciences, 12(4), 495-547.

Lesh, R., Post, T., & Behr, M. (1987). Representations and Translations among Representations in Mathematics Learning and Problem Solving. In C. Janvier, (Ed.), Problems of Representations in the Teaching and Learning of Mathematics (pp. 33-40). Hillsdale, NJ: Lawrence Erlbaum.

Papert, S. (1980). Mindstorms : Children, computers, and powerful ideas. New York: Basic Books.

Papert, S., & Harel, I. (1991). Situating constructionism. Constructionism, 36(2), 1-11.

Stokes, P. D. (2005). Creativity from constraints: The psychology of breakthrough. Springer Publishing Company.

Short online video tour of Design Math at the Project School Middle School https://iu.box.com/v/designmath

Acknowledgements. This project was possible by the support of the NSF under *Re-Crafting Mathematics Education: Designing Tangible Manipulatives Rooted in Traditional Female Crafts* grant No. 1420303 awarded to Dr. Kylie Peppler. We thank our students for an inspiring school year and their supportive parents. Thank you to Ms. Cathy, Sandy, Karla, Sara, Sophia, Anna, Naomi, Kate, Ed, Lori, Janis, and Tony.