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THE INTERDISCIPLINARY JOURNAL OF PROBLEM-BASED LEARNING

VOICES FROM THE FIELD

Project-Based Learning and Design-Focused Projects to Motivate Secondary Mathematics Students

Kelly W. Remijan, PhD (O'Fallon Township High School)

Abstract

This article illustrates how mathematics teachers can develop design-focused projects, related to project-based learning, to motivate secondary mathematics students. With first-hand experience as a secondary mathematics teacher, I provide a series of steps related to the engineering design process, which are helpful to teachers in developing design-focused projects, describe various projects that have been developed and implemented within my classroom, and share project artifacts illustrated by pictures, student work, and student comments. Referring to the MUSIC Model of Academic Motivation and reflecting upon personal observations, student outcomes, and student comments, I provide personal insight on how design-focused projects can be perceived to enhance student motivation within the mathematics classroom.

Keywords: mathematics, motivation, project-based learning, design, secondary education

Introduction

With many middle-school and high school teachers encountering students who find mathematics “uninteresting and irrelevant,” or students who lack the motivation to learn mathematics (NCTM, 2000, p. 371), mathematics teachers must

work to keep students involved in relevant classroom activities, assign projects that make connections between mathematics and students’ daily lives, and allow students multiple avenues to display what they have learned. Learning experiences based in the workplace have also proved effective in motivating students who are at risk of becoming disengaged from school. (NCTM, 2000, p. 374)

Mathematics teachers must seek out relevant activities or projects that engage students in real-life problem solving where they “analyze a problem in the community . . . or use geometry [to] solve a design problem” (NGA Center for

Best Practices & CSSO, n.d.b, para. 5). While “story problems” are often found in the mathematics curriculum, such “structured” problems often do not transfer to real-life, fail to provide students with meaningful learning opportunities (Jonassen, 2000), and negatively impact student motivation (Savery, 2006). Consequently, as various professions such as those associated with engineering or architecture involve “complex and ill-structured design problems” (Jonassen & Hung, 2008), design-focused projects connected to engineering and architecture within the mathematics classroom can provide students with opportunities to solve meaningful problems, which can positively impact student motivation.

To motivate students to learn and apply mathematics through the use of design-focused projects, teachers should consider implementing projects that incorporate problem- and project-based learning. To utilize problem-based learning, Torp and Sage (1998) highlight essential components for actively engaging students in the process: (1) Meet the problem, (2) Identify needs, (3) Define the problem, (4) Gather

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and share information, (5) Generate solutions and determine the best solution, and (6) Present the best solutions. Alternatively, to help promote project-based learning, Grant (2002) identifies a series of project requirements: (1) an introduction to “set the stage”; (2) a task or driving question; (3) a process that results in the creation of an artifact; (4) subject-matter experts or other resources; (5) scaffolding to assess individual and group progress; (6) collaborations, including teams, peer reviews, and external specialists; and (7) opportunities for reflection and transfer, such as classroom debriefing sessions.

Although problem-based learning (PBL) and project-based learning (PjBL) are both student-centered methods (Dole, Bloom, & Kowalske, 2016) that deal with real-world problems and positively impact student motivation (Savery, 2006; Tamim & Grant, 2013; Torp & Sage, 1998; Wolk, 1994), the two are different in focus.

Whereas PBL begins with a problem for students to solve or learn about, PjBL begins with an end product or “artifact” in mind. The problems in PBL are ill structured to mirror the complexity of real life; the problems in PjBL use a production model and, as such, mirror the real-world production model. In PjBL, the end product is the driving force, while the defined problem is the driving force in PBL. (Dole et al., 2016, p. 1)

Design-focused projects, which emphasize process and product, often lead to a hybrid model (Prince & Felder, 2006) that integrates both problem- and project-based learning (Jones, Epler, Mokri, Bryant, & Paretti, 2013). As a result, classes “that deal with process or product design and development” are “well-suited” for hybrid problem- and project-based learning opportunities (Prince & Felder, 2006, p. 22), which ultimately enhances motivation by allowing “every student to experience success” (Wolk, 1994, p. 44).

While the motivating potential of a job is dependent on the design of the job (Hackman & Oldham, 1976), the motivating potential of an academic class is dependent on the design of the class (Jones, 2009, p. 273). Academic motivation is defined as “a process that is inferred from actions (e.g., choice of tasks, effort, persistence) and verbalizations . . . whereby goal directed physical or mental activity is instigated and sustained” (Jones, 2009, p. 272). In order to answer the question, “What can instructors do to . . . motivate students to engage in learning?”, Jones (2009) developed the MUSIC Model of Academic Motivation as a guide for designing coursework or project work that affects the needs, perceptions, and behaviors of students. When instructors of any level or discipline incorporate the five components of the MUSIC model in the design of their course, students are more inclined to feel eMpowered, perceive what they are doing is Useful, experience Success, take an Interest

in a topic, and believe that others Care about their work (Jones, 2009). While the MUSIC model originates within higher education and has been found to impact the motivation of students enrolled in engineering classes incorporating problem-based learning (Jones et al., 2013), elements of the MUSIC model and the impact on student motivation within elementary, middle school, and high school settings can be found by retroactively analyzing teacher comments and experiences, in addition to other earlier research from the Center of Problem-Based Learning at the Illinois Math and Science Academy (Torp & Sage, 1998). As the MUSIC Model provides the framework necessary to engage students in motivational activities that increase student perceptions in all of the MUSIC components (Jones, 2009), mathematics teachers have the potential to motivate secondary students by engaging them in design-focused projects that incorporate all five MUSIC components and embrace the motivating potential of real-life project work.

Designed-Focused Projects in the Mathematics Classroom

After implementing various projects within my mathematics classroom, which were end-product focused, I was introduced to the idea of problem-based learning upon acquiring a grant associated with the *Illinois Mathematics and Science Academy*. Learning about the essentials of problem-based learning, integrating concepts associated with project-based learning, and utilizing the MUSIC Model of Academic Motivation as a guide, I established a list of student experiences that I felt were a priority for enhancing student motivation and overall learning:

1. Apply a variety of skills using analytical and creative talents to solve meaningful problems.
2. Take on individual responsibilities as well as responsibilities within a team.
3. Experience freedom to develop their own innovative ideas.
4. Receive feedback during the design process from experts in the field.
5. Gain recognition from the community while sharing ideas outside of the school.

I established broad goals to support student engagement before focusing my attention on exposing students to real-life situations that would provide them with the opportunity to investigate, research, communicate, learn, and apply various mathematics skills.

To develop meaningful problems, I worked with my colleague, an art teacher, to reflect on and discuss situations facing the local and surrounding communities. Having our own

unique ways of thinking, we brainstormed ways in which we could utilize the community, connect our students to the community, and involve our students in becoming a part of the solution to many of the problems facing the local and surrounding communities. Whether reading the newspaper about the local affiliate of Habitat for Humanity wanting to build a new house in an adjacent community, or the city considering building a new library or new fire station, each real-life situation involved a discussion on how to engage students with purpose, making contact with community members, creating partnerships, setting up meetings with community members, presenting ideas to community members, and asking for support from community members in terms of information, name recognition, and venue use for a public open house.

Over a course of five years, I have developed and implemented various design-focused projects within my high school mathematics classroom involving approximately 330 mathematics students (51% male and 49% female) enrolled in honors geometry, which follow.

(1) Project DESTINE (Designing Energy-efficient Shelters Together In Neighborhoods-Everywhere)

This project, which was the first problem-based learning project implemented into my mathematics classroom and was supported by the *Illinois Mathematics & Science Academy* (IMSA) as part of the Illinois Innovation Talent Pilot Grant, was developed to have geometry students design a house for the proposed sustainable development called *Tuscany Trails*, which was to be eco-friendly, cost effective, appealing, and marketable in O'Fallon, Illinois. The strengths of this project were the involvement of various partners such as city planner, developer, builder, and architect, in addition to the ability to visit another sustainable development, tour houses at various building stages, and meet with an additional developer, civil engineer, and environmental biologist.

(2) O'Fallon Township High School (OTHS) for Habitat

This project was developed to have geometry students design a house for the Lewis & Clark Habitat for Humanity–Collinsville Chapter, which was to be eco-friendly, energy efficient, and cost effective for both *Habitat* to build and the selected family to maintain. The strengths of this project included the involvement of a local architect, who met with students at our school, and the ability to host a fundraiser at the local mall with the family selected to receive the next *Habitat* house. One challenge for this project involved not being informed of the exact location of where the house was to be built.

(3) Project Fire RESCUE (Reaching out and Educating Students on Caring about and Understanding the Essentials of fire safety)

This project was developed to have geometry students design a new fire station for the O'Fallon Fire Department that would meet the city's current and future needs. The strengths of this project included the involvement of four architects from Arcturis Architectural Firm and the ability to organize a field trip where students toured three fire stations and met with various firemen. Unlike the previous two projects, another strength of this project was the fact that the city planner was able to provide the specific location of where the new fire station was approved to eventually be built.

(4) Library VISION (Vision Involving Student Input On Needs)

This project was developed to have geometry students design a new public library for the city of O'Fallon that would meet the city's current and future needs. The strengths of this project included the involvement of three architects from the firm of Bond Architects, Inc. and the culminating open house held at a local fire station in conjunction with the Fire Explorer's Spaghetti Fundraiser. In regard to challenges, while the school would not approve a field trip due to a temporary stoppage of field trips, students were able to conduct preliminary research on their own at the local library. In addition, the location of the proposed library could not be provided by the city.

(5) Zoo VISION (Vision Involving Student Input On Needs)

This project was developed to have geometry students create a design for the old sea lion facility that would meet the goals of St. Louis Zoo in Missouri. The strengths of this project involved the continued partnership with Bond Architects, Inc., as well as the culminating open house held at the St. Louis Zoo. While blueprints of the existing facility to be replaced were provided by the zoo, a field trip was again not approved by the school due to a temporary stoppage of field trips.

Students involved in the projects listed above were primarily ninth grade students at O'Fallon Township High School. O'Fallon Township High School is a ninth through twelfth grade high school only district located in O'Fallon, Illinois, a community adjacent to Scott Air Force Base and a suburb of St. Louis, Missouri, with over 200 employees serving approximately 2,500 students. The first project, *Project DESTINE*, involved ninth and tenth grade honors geometry students, while the other projects involved only ninth grade students as a result of my teaching assignment and the formation of two campuses: one campus for ninth graders only and

a second campus for tenth through twelfth grade students. The ethnic diversity of the district and the honors classes was primarily Caucasian, with 33% of the school population classified as being of minority background and 21% classified as low income (Illinois State Report Card).

Designing a Motivating Project for Mathematics Students

Since engineering is a critical component of STEM and STEAM education (Science, Technology, Engineering, Art/Architecture, and Mathematics) and the process of mathematical thinking follows the same path as the steps for the process of engineering design (Stoner, Struby, & Szczepanski, 2013), each problem or project implemented within my mathematics classroom involved students utilizing the engineering design process. The engineering design process, which led my students through the process of solving a real-life problem during each project, is defined by NASA and the International Technology Education Association (2009, p. 1) as a

model for analyzing and solving problems related to the creation or improvement of products, processes, and services . . . driven by purpose and requirements; is systematic, iterative, and creative; develops multiple solutions to a problem; and assists in the selection of the best solution from among various alternatives.

A 12-step engineering design process, consistent with the essentials of problem-based learning (Torp & Sage, 1998), provides educators with a process that encourages student engagement, exploration, explanation, extension, and evaluation (NASA & ITEA, 2009; Illinois Report Card, 2013–2014):

1. Defining a problem,
2. Brainstorming,
3. Researching and generating ideas,
4. Identifying criteria and specifying constraints,
5. Exploring possibilities,
6. Selecting an approach,
7. Developing a design proposal,
8. Making a model or prototype,
9. Testing and evaluating the design using specifications,
10. Refining the design,
11. Creating or making the final solution, and
12. Communicating the processes and results.

Understanding the National Council of Teachers of Mathematics (2000) five Process Standards (Problem Solving, Reasoning and Proof, Communication, Connections, and Representation) and aligning with the required Common Core's eight Standards for Mathematical Practice (NGA Center for Best Practices & CSSO, n.d.b), I modified NASA's 12-step

design by integrating components of the MUSIC Model for Academic Motivation (Jones, 2009) and by highlighting mathematical process and practice. To increase student empowerment, numerous opportunities were included within the design process for students to discuss ideas, make choices, or apply changes. To increase student perceptions of Usefulness of the project, student Success and Interest, and the belief that the professionals in the field and members of the community Care about their work, opportunities to engage with experts in the field and share with members of the community were included in the design process as a way for students to acquire feedback and recognition and receive exposure to potential future careers and community service. Finally, to highlight mathematical processes and practice, calculations pertaining to square footage, volume, and costs were added to the design process, in addition to real blueprint analysis and scale model building.

There are various steps of design-focused projects within the mathematics classroom, which follow:

1. Determine the Problem,
2. Brainstorm,
3. Conduct Research and Preliminary Calculations,
4. Generate Ideas,
5. Acquire Professional Feedback,
6. Make Improvements/Prepare a Proposal,
7. Present a Design Proposal,
8. Select the Best Solutions and Make Improvements,
9. Analyze Architect Created Blueprints,
10. Calculate Costs,
11. Build a Model, and
12. Present Final Projects and Gain Community Recognition.

As academic motivation is a process involving effort, supported by actions and verbalizations (Jones, 2009), the remainder of this paper describes the design process utilized by my students, indicates how teachers can implement design-focused projects to motivate secondary mathematics students, and provides teacher insight on how design-focused projects impact student motivation as perceived by teachers through observations, teacher analysis of student artifacts, and teacher reflection on student comments. While pictures and student artifacts show the results of students' efforts, comments shared directly by students acquired from open-ended questions, such as "What did you learn?" or "What did you like?", found on the students' reflection/project feedback forms completed by students throughout the various steps of the design process, and comments acquired from students' final PowerPoint presentations help to verbalize how the design process can be motivating for students as defined by the MUSIC Model of Academic Motivation. By describing the steps in the design process and analyzing and reflecting upon my personal observations of student outcomes

depicted through qualitative data, this paper provides a first-hand account on how I perceived student motivation to improve as a result of design-focused projects and themes associated with the MUSIC Model of Academic Motivation. Furthermore, this paper provides a guide to teachers on how they can implement their own design-focused project and, consequently, enhance student motivation within the mathematics classroom.

Step 1—Students Determine the Problem

To make learning relevant, students are presented with a problem in the form of a letter provided by a real person or a real organization, with a real need for help. After carefully reading the letter, students critically review it and identify the problem in the form of a question. In *Project Fire RESCUE*, students read a real letter sent and signed by our city's mayor and determine a problem statement: How can we as geometry students design a new fire station for the city fire department that will meet the city's current and future needs? While the initial letter is significant in that students are asked directly by the mayor to assist the city with creative ideas, the problem also proves to be significant as students are asked to showcase ideas, designs, and models to the public at a community venue, such as a local fire station, with *Project Fire RESCUE*.

Step 2—Students Brainstorm

After identifying the problem, students determine what they know and what they need to know and devise a plan to acquire the necessary information. While it is important for the teacher to act as a facilitator during the brainstorming phase by reiterating the questions of "What do we know?" or "What do we need to know?", it is also important for the teacher to remain an overall project manager who keeps students focused on the design aspect of the project.

Step 3—Students Conduct Research and Preliminary Calculations

Once students determine what they need to know, they assign research topics and research all necessary components. *Project Fire RESCUE*, for instance, required students to research topics such as fire stations, energy-efficient materials, and design strategies. Another project, entitled *Zoo VISION*, also involved students researching energy-efficient materials and design strategies, but also included zoo design and animal needs in order to design a new exhibit for the local zoo. As the Internet can effectively enhance student learning, technology can also help students share data and learn from each other. After creating a class Web page and individual group Web page through our school's Edline system, students were able to upload and share information with the entire class or specific group members; thus, all students can benefit from their peers' research.

While information can often be found using the Internet, information must also be obtained directly from experts in the field. During *Project Fire RESCUE*, students needed to know the location of the proposed site for the new fire stations, so the city planner was contacted via e-mail and responded with an aerial map of the proposed location. Using the aerial map, students then calculated the site area in order to determine the maximum area of a potential fire station. Although communicating with experts via e-mail is helpful, talking to experts, visiting sites in person, and gathering first-hand evidence through personal photographs or measurements provide students with the most efficient, accurate, and memorable research. During *Project DESTINE*, for instance, in which students were asked by a local developer to design energy-efficient homes for a new green development within the community, students visited a sustainable development in a nearby community where they toured homes at various building stages (see Figure 1). During the field trip, they interacted one-on-one with various experts including a developer, builder, civil engineer, architect, and environmental biologist.



Figure 1. Students tour houses in various building stages of sustainable development during Project DESTINE.

When teachers build partnerships with professionals and connect students to people who use math in their daily lives, students can be motivated. During *Project DESTINE*, Peter S. explained that "Mr. Schroeder [the developer] was very motivational in the way that he motivated us to try to come with our own interesting innovative ideas and take risks, relating his own life experiences to us." Another student, Taylor A., also shared how such an experience can make an everlasting impression:

He [the builder] stressed the importance of asking questions and thinking outside the box because we may be the people that come up with even newer green technology that could change the way we live. He said

to be open to communication and operate together, but don't trust everything that you hear or read. Overall, I believe that this field trip was a learning experience that I will never forget.

When students experience research through field trips that take them out into the community, they can experience math, connect math to real life, and understand its purpose.

Even though field trips provide students with amazing opportunities to connect class work to the real world while gaining hands-on experience, sometimes field trips are not possible. While we were unable to organize a field trip for the *OTHS for Habitat Project*, we were able to have the architect working with us on the project visit our school to talk about the building process and to answer questions. Furthermore, students conducted conference phone calls with the chairperson for the local Habitat chapter. During *Library VISION*, however, where students were asked by the city library director to design a new library, a team of professionals consisting of an architect, engineer, and city library director visited our school. Working in teams with each student assuming a specific role (architect, engineer, or designer), each team member met with a different expert and was responsible for obtaining information specific to his or her assigned role. By giving each student an identity and a specific role within the project, students were motivated by the responsibility for obtaining and sharing specific information within their group.

Step 4—Students Generate Ideas

After reviewing and analyzing research, students generated design ideas and then shared rough elevation sketches and floor plan ideas within their group. Discussing and combining ideas, each group developed an overall plan



Figure 2. Students collaborating on a scale drawing of a new library design during the Library VISION project.

illustrated on graph paper by scale elevation drawings and scale floor plan drawings, as shown in Figure 2 during the *Library VISION* project.

Step 5—Students Acquire Professional Feedback

Once students generated ideas and developed a rationale to support them, they had the opportunity to share their ideas with an expert. Acquiring feedback from professional architects, students had the ability to reflect on their designs and to make improvements as desired. This can be seen in Figure 3, where students involved with the *Zoo VISION* project are shown sharing their ideas for a new Panda Exhibit as they met with Sue Pruchnicki, Principal Architect and Co-Owner of Bond Architects, Inc.



Figure 3. Students discussing floor plan and elevation ideas with Sue Pruchnicki, principal architect and co-owner of Bond Architects, Inc.

Step 6—Students Make Improvements, Finalize Solutions, and Prepare a Proposal

After acquiring feedback from architects, students make improvements and finalize their solutions using Google SketchUp. For example, see Figure 4 (next page) for a sketch created by Hour 01-Group 12 during the *Library VISION* project.

An addition to including a floor plan in their design, students included their own elevation drawings within their PowerPoint proposals, as shown in Figure 5 (next page) during the *Zoo VISION* project by Hour 02-Group 06.

Step 7—Students Present Their Design Proposals to the Class

After creating design proposals, each group presents their ideas and rationale to the class, as shown in Figure 6 (two pages ahead) during the *Library VISION* project.

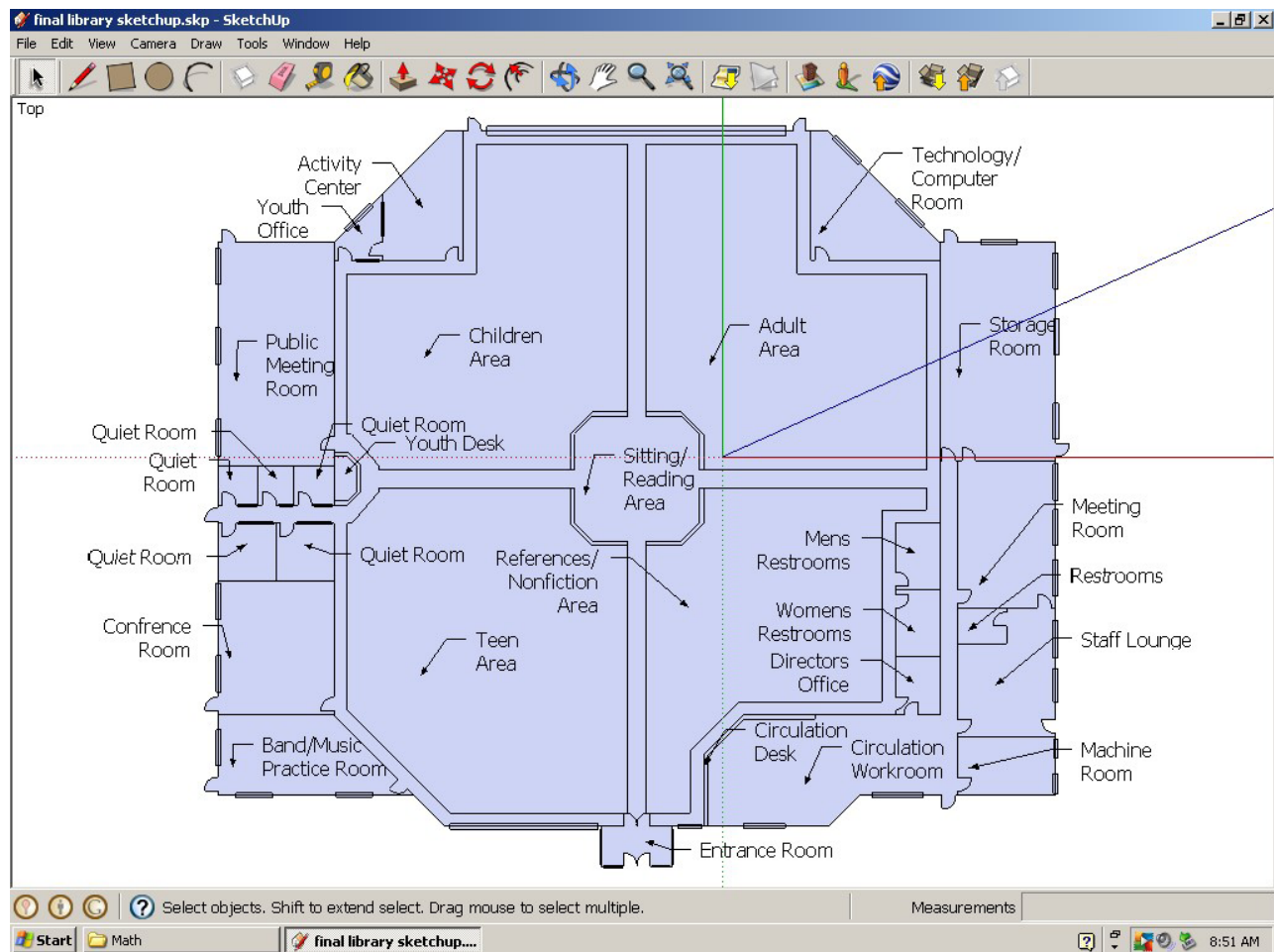
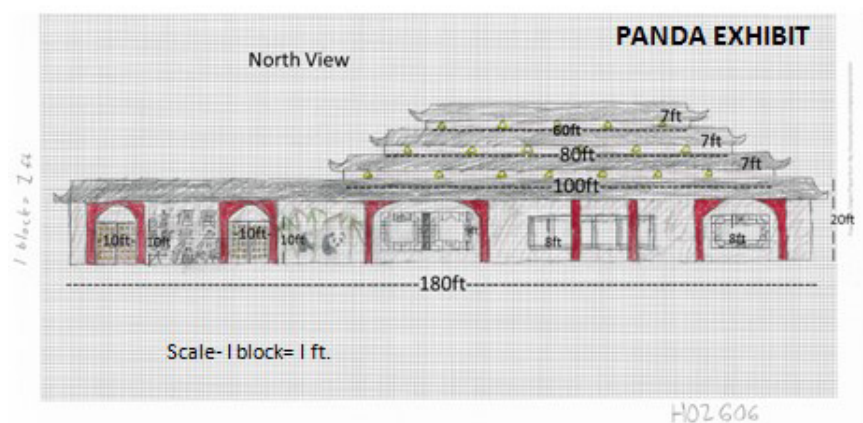


Figure 4. Example of a student created library floorplan made using Google Sketchup during the Library VISION project.

Zoo VISION project Students Sketch Elevation Ideas



- Chinese style building since Panda's origin and Chinese culture
- Windows on taller part so sun can come through
- Rectangle-shaped building is easier and cheaper to build
- Large doors for heavy traffic

Figure 5. Example of a student-created elevation drawing of a new panda exhibit during the Zoo VISION project.



Figure 6. Students presenting a design proposal during the Library VISION project.

Step 8—Students Select the Best Overall Solution & Make Improvements

Group members work together to evaluate and determine the strengths and weaknesses of each team's proposal. As a class, students then determine the best overall solution and identify changes or improvements to strengthen it (see Figure 7).

Step 9—Students Analyze Architect-Created Blueprints

Using floor plans and elevation drawings selected by each class and incorporating changes recommended by each class, architects developed real blueprints and elevations. See Figure 8 for an example created by Bond Architects Inc. during the *Library VISION* project.



Figure 7. Students analyzing classmates' proposals to determine strengths and weaknesses of various designs during the Zoo VISION project.

During the *Zoo VISION* project, architecture students from the local community college created final blueprints of the math students' designs for a new panda exhibit (see Figure 9, next page), which students then analyzed in preparation of calculations and model construction.

It is important to note that while step 9 could be eliminated in the design process if an architect was unwilling or unable to make blueprints, involving an architect is a vital component to increase student perceptions of Usefulness of the project, student Success and Interest, and the belief that the professionals in the field and members of the community Care about their work. Having an architect, or architectural student(s), involved in the project is helpful in creating real blueprints where students have the opportunity to see their ideas come

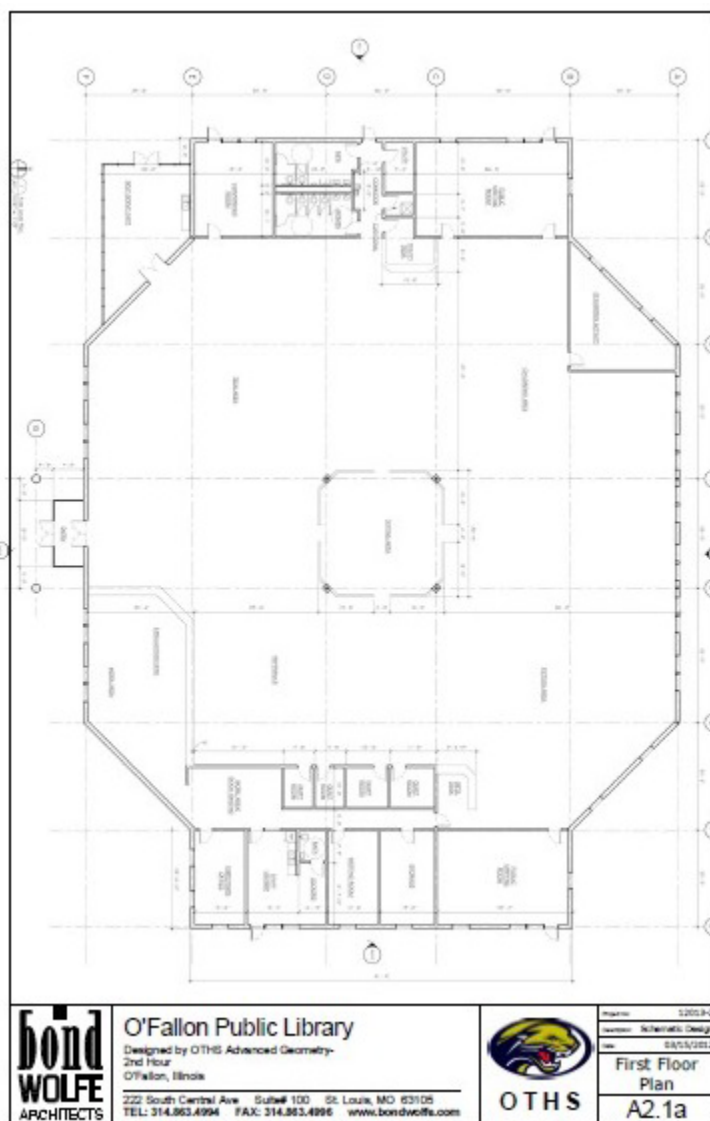


Figure 8. Floorplan blueprints developed by Bond Architects, Inc. from student inspired ideas and Google Sketchup drawings during the Library VISION project.

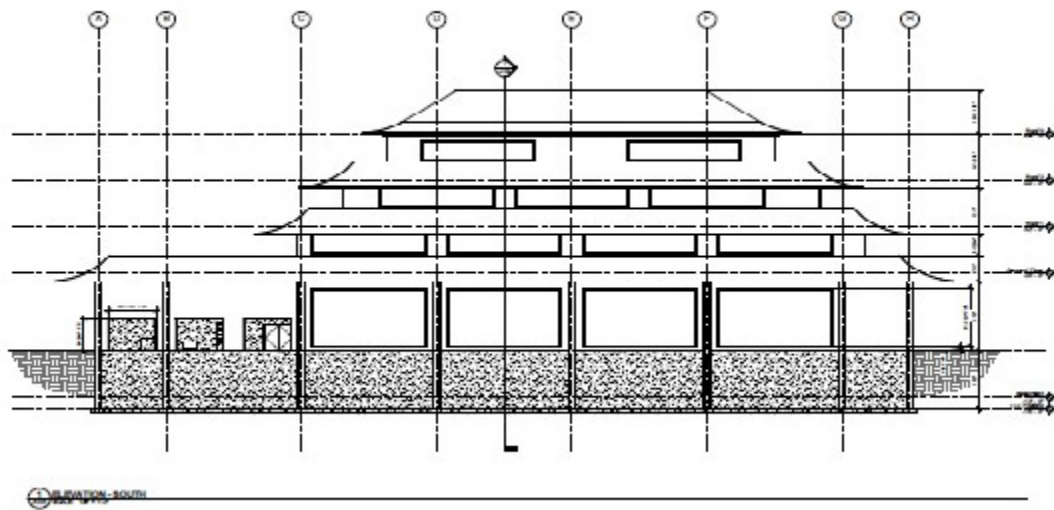


Figure 9. Elevation blueprints developed by Bond Architects, Inc. from student inspired ideas and Google Sketchup drawings during the Zoo VISION project.

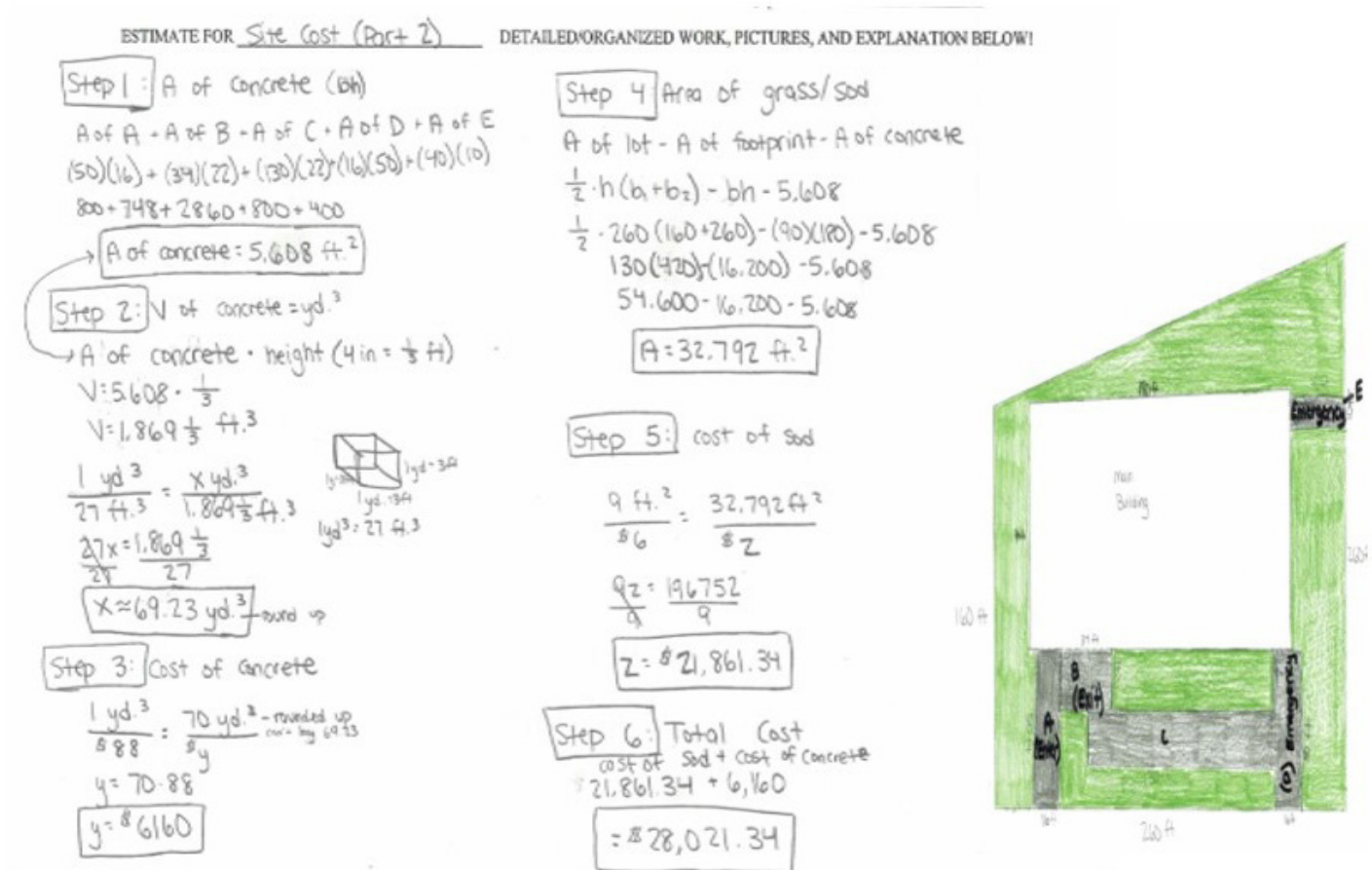


Figure 10. Example of student calculations to determine landscaping cost during Project Fire RESCUE.

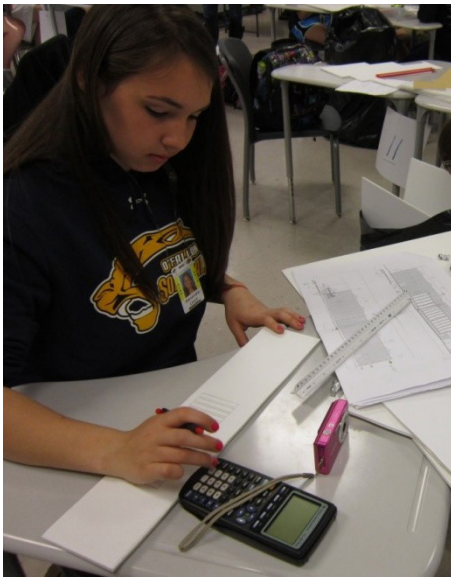


Figure 11. Student working on model calculations during the Zoo VISION project.

to life, read and analyze real blueprints, and accurately use the given blueprints to build a scale model. Working off of real blueprints allows students to practice and apply mathematical skills crucial for a mathematics or geometry class.

Step 10—Students Calculate Cost Estimates

After receiving final blueprints from architects or architectural students, math students draw pictures and conduct calculations specific to their roles (architect, landscape architect, engineer, designer, project manager, etc.). One example, as shown in Figure 10 (previous page), illustrates how one student, Prem P., demonstrated his learning as his group's landscape architect through the process of calculating costs such as concrete and sod related to the Zoo VISION project.

Step 11—Each Group Builds a Model

While each member of a group is responsible for conducting specific research, performing various calculations, scanning calculations, displaying research in a group PowerPoint, and providing rationale within a group presentation, all members of each group must also work together to build a 3-D scale model of the selected design. Students must effectively model mathematics by building a 3-D model that is well-built (sturdy and neat), accurately depicts the given blueprints, and clearly represents desired materials, colors, and textures. As students had autonomy in their original design plans, students also had freedom in building their models. Although groups within each class are utilizing the same blueprints, each group had the ability to make their model unique: they could determine what materials to use for the real building, what materials to use to build the model, and what

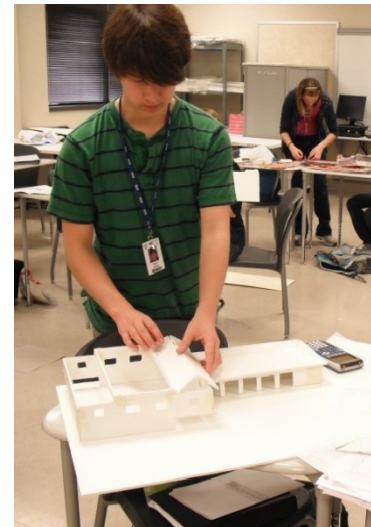


Figure 12. Student building a model of a new fire station during Project Fire RESCUE.



Figure 13. Students discussing their model and design plan during a public exhibit held at the Saint Louis Zoo at the conclusion of the Zoo VISION project.

model materials and colors to use to reflect actual building materials. Figure 11 depicts a student working on model calculations during the Zoo VISION project. Figure 12 illustrates another student building a model during Project Fire RESCUE.

Step 12—Students Present Final Projects and Gain Community Recognition

After building a scale model and constructing a PowerPoint presentation to organize and present ideas, teams share their models and PowerPoints with the community at venues outside of school, such as the mall, fire station, library, and zoo. At the Zoo VISION open house, as shown in Figure 13, math students conversed with the public at the nationally recognized zoo and discussed their projects. Models were on display and PowerPoint presentations ran continuously on

laptops surrounded by artwork created by fellow art students.

Not only are community open houses excellent opportunities for students to share what they have learned, but they also allow students to be recognized by the community. Furthermore, when projects and open houses allow students to give back to the community, students can develop a sense of citizenship. While *Project Fire RESCUE* was held at a local fire station in conjunction with the Fire Explorer's Spaghetti Fundraiser, the Habitat for Humanity open house was held at the local mall where students participated in a Habitat for Humanity stud signing, which raised \$667 for the local affiliate. When students engage in real-world mathematics, develop innovative design solutions, and share what they are learning outside of the classroom, the community has an opportunity to see the amazing learning that is occurring in our schools.

Observations of Design-Focused Projects Enhancing Student Motivation

When design-focused projects are developed and implemented successfully, students are motivated to communicate and collaborate within the classroom and community to devise innovative solutions to real-life problems. As "teachers motivate students by encouraging communication and collaboration and by urging students to seek complete solutions to challenging problems" (NCTM, 2000, p. 24), "teachers need to take special initiatives to find . . . integrative problems," (p. 359) which can be implemented into meaningful projects that enhance student motivation. Thus, project- and problem-based learning should be considered as tools to create motivating opportunities to engage mathematics students.

The 12-step process identified in this article not only provides students with a systematic process of how to solve a real problem, it also provides teachers with various opportunities to assess student learning. By collecting evidence, formally and informally, throughout each step of the engineering design process, I was able to assess student reasoning, strategies, procedures, and mathematical skills. As "evidence from a variety of sources is more likely to yield an accurate picture of what each student knows and is able to do" (NCTM, 2000), I was able to acquire evidence of mathematics learning and assess student learning through observations, one-on-one conversations, discussions with experts involved in the project, hand sketches, computer drawings, calculation sheets, PowerPoints, models, and responses to open-ended questions such as "What did you learn?" and "How did you use math?"

Jones et al. (2013) utilized student responses to open-ended questions pertaining to an engineering project as evidence of students identifying elements of academic motivation as defined by the MUSIC Model of Academic Motivation. Similarly, this article utilizes the responses of secondary

mathematics students to open-ended questions such as "What did you like?", which were acquired from student reflection forms completed throughout various stages of the twelve steps and from final thoughts of students shared on PowerPoint slides during their final project presentations. The summary of comments, along with specific quotes, shared in this paper are reflective of the majority of students and provide evidence of how the various projects presented opportunities for students to become motivated and engaged.

Observations of Empowerment

With design-focused projects, students were empowered through support and on-going encouragement to identify problems, brainstorm, generate ideas, devise their own creative solutions, select choices, and make changes as necessary. While each project was different, student consensus was that they recognized how they were in control of their own learning and appreciated having the ability to make their own decisions. One student, Alex H., shared during the *Zoo VISION Project*, "I liked the chance to work together and brainstorm ideas during the various stages of the project." Sam J., during *Project DESTINE*, also expressed positive comments, stating:

I liked that this project called for a lot of thinking and creativity. Most projects (especially in math class) are very boring and require one frame of mind whereas this project made us use all parts of our brain and then mix it together to find solutions.

Students commented on how they liked having the ability to come up with their own design in addition to having the freedom to select materials and color choices for their model. Observing students work during the design process, reviewing student ideas expressed through hand sketches and other mediums, and reading student comments about what they learned and what they liked about the project, it became apparent that students not only learned mathematics, but also were motivated by having a sense of empowerment as they engaged in the project.

Observations of Usefulness

Understanding how "it is critical to design the project in a manner that can be seen as useful and relate to as many interests as possible if the intention is to fully motivate students" (Jones et al., 2013, p. 60), the various projects identified in this article not only connected class material to real-life problems, but also showed students how their project work could be useful to others within the community. This was expressed by students on various reflection forms and during final project presentations. One student, Ashley G., shared in her project presentation that she liked "the way

that math had an importance in real life and not just in math class.” Alex S. agreed, stating that he liked “the ability to practice skills learned in class on a real-life project and not just random problems.” Other students, like some involved with the *Zoo VISION* project, shared that they liked building something with a purpose and liked working interactively with the zoo.

Observations of Success

Student perception of success can be nurtured with ongoing feedback (Jones et al., 2013). Students involved in the design-focused projects that I implemented into my mathematics classroom had the opportunity to receive feedback from me (the teacher), peers, professionals in the field, and various community members. They also had the opportunity to experience success through a variety of tasks such as sketches, scale drawings on graph paper, drawings on Google SketchUp, discussions with architects, cost calculations, PowerPoint presentations, and 3-D scale models. At the conclusion of the *Zoo VISION* project, Hannah F. shared, “I enjoyed working with the architects, thinking creatively, and making our design come to life.” Student success was apparent throughout each step, such as the conclusion of the project where each group presented a 3-D scale model and final PowerPoint presentation of their work.

At the completion of all five projects, the majority of students not only voiced that they were happy that they had completed the project, but also shared that they were generally proud of what they had accomplished. This sentiment was also expressed by group 05-10, who shared in their final slide of their *Project Fire RESCUE* presentation that their favorite part of the project was “seeing our final product and feeling that we had reached success.” Jones (2009, p. 276) stated that “students need to believe that if they invest effort into the course, they can succeed.” Similarly, group 05-08 shared that they learned that “you can never accomplish a great task without the time and effort put towards it.” While the work displayed throughout the design process, including final PowerPoints and models produced by each group, was successfully completed, the comments students shared during their final presentations solidified that they felt they had completed the project successfully and felt a sense of pride in what they had accomplished.

Observations of Interest

When projects provide opportunities for students to receive feedback from professionals in the field, in addition to opportunities to reflect on and improve their work, student understanding and student interest can also increase (Jones et al., 2013). Furthermore, when teachers help students understand the value of what they are doing, student interest can

be developed further (Hidi & Renninger, 2006). Throughout the various design-focused projects, several students shared that they liked having the chance to experience what it is like to be an architect. Most project work does not occur in the regular classroom, but instead in the school “smart-link” room; thus, some students shared that they simply liked not being behind a desk and liked building something instead of doing problems from the book.

While some students developed an interest in the project because of a potential career or change of pace, the majority of students expressed an interest in the various projects based on the situation in which they could make a real impact. Student Jenni I., for instance, who was involved in the *Library VISION* project, shared, “I liked how we got the chance to suggest ideas for the new library. It will be nice to know that our contribution had some influence on the new library that will be built.” Another student, Whitney W., said, “creating a possible design plan for the future O’Fallon Library was an honor.” When projects are real-world oriented and designed to provide students with opportunities to assist the community, students are motivated to provide the community with viable solutions that have the potential to be useful in real-life. As a result, student interest can be developed by teachers when they consciously expose students to potential careers, change the venue of where learning takes place, and make project work meaningful, lifelike, and connected to the community.

Observations of Caring

Throughout the various steps of the projects, students commented that they perceived a sense of caring, whether from their classmates within their working groups or professionals from various fields. While most students shared that they liked working in a team and learned how to “work with people in an effective way,” others shared how the professionals they worked with influenced them in their success. Student Peter S., for instance, shared during *Project DESTINE*, “Mr. Schroeder [the developer] was very motivational in the way that he motivated us to try to come with our own interesting ideas and take risks, relating his own life experiences to us.”

While interaction with professionals involved with project work is important throughout the process and helps to show students that others care about their ideas, recognition at the completion of the project provides students with a final sense of accomplishment and shows that their work and final product is appreciated and valued by the entire community. At the conclusion of *Project DESTINE*, a community open house was held where the public was invited to learn about environmentally friendly design and view student designs. Various community members attended the event and shared how impressed they were with the students’ overall projects

and solutions. Mr. Tim Dain, a community member who attended the open house, formally praised the students' work in the local newspaper:

I think this is unbelievable. They have done some really unique things with their home. They have invested time in researching the products and they understand. . . . This is the generation that gets it. . . . This is the generation that needs to get it. (Raeber, 2009, p. A7)

When design-focused projects culminate at an event held at a public venue with newspaper reporters in attendance, students are motivated with the knowledge that their work will be seen by members of the community, who will care about their work.

Although most students' comments that relate to a sense of caring often pertain to group and professional interaction, one of my students, Alex S., sent me a letter following the *Zoo VISION* project, which helps to explain what some students may feel but may not express directly to me regarding their thoughts of me (the teacher) caring about them:

I would like to thank you for all of your hard work to teach my fellow classmates. . . . I would also like to thank you for spending the time to connect our lessons to real life things. . . . Thank you for all of the time you have spent on the zoo project as well. I find it very interesting to get involved with a real life situation and use my skills for something that may come true. I know that this project has been a lot of work for you so thank you for taking the time to enhance our experiences with geometry. Thank you for all that you have done this year. I want you to know that I and my peers appreciate all the work that you put into our lessons.

Final Thoughts

As "too many students disengage from school mathematics, which creates a serious problem not only for their teachers but also for a society that increasingly depends on a quantitatively literate citizenry" (NCTM, 2000, p. 371), teachers must be willing to create a learning environment that connects students to the larger community, provides them with purpose, engages them in mathematics, and encourages innovative problem solving. Designing a motivating project for students first requires the teacher to brainstorm. Brainstorming with teachers of other disciplines can provide mathematics teachers with different perspectives in addition to collegial support and additional resources. Working with my colleague, who had professional connections with the mayor and city planner as a result of being part of the City of O'Fallon Arts Commission, I was able to establish connections and develop

a strong working relationship with the leaders of our community who were committed in helping out in any way possible. From those relationships, I was able to learn about the needs of the city and form other connections with business members who had previously done work with the city. While designing motivating projects for mathematics students takes time, the potential impact for student motivation and learning is well worth the teacher's extra effort.

Using the 12-step process outlined in this article, teachers can develop and implement project-based learning and design-focused projects that empower students, create a sense of usefulness, provide opportunities for success, increase student interest, and show students that people within the community care about their work. Having a 12-step process not only assists students in solving a real problem, which could ultimately be quite messy without a structured process, but also assists teachers with a proactive system that promotes progress checks, feedback, and formal evaluation throughout the entire process. While the majority of students participating in the five projects illustrated in this paper voiced positive opinions of the project in which they participated, there were a few students that expressed difficulty working with others at various points of the project. It is important to note that teachers must be proactive project managers who continually monitor group and individual student progress, address problems, tensions, or difficulties among group members, and continually motivate students to communicate, collaborate, and create an end product in which they have a sense of pride and great accomplishment.

Although this paper attempts to show how design-focused projects can motivate secondary mathematics students, I personally feel that these projects also have a positive impact on the teachers who incorporate them into their classrooms. Thus, it would be interesting to see future research conducted on how design-focused projects impact secondary mathematics teachers. Having developed and implemented the various projects described in this article, I would encourage other secondary mathematics teachers to collaborate with colleagues outside of the mathematics department and establish partnerships with members of the community to develop design-focused projects that can motivate secondary mathematics students.

Design-focused projects implemented within the mathematics classroom not only provide students with the opportunity to apply mathematics and thinking skills to real-life problems, but also connect students to the greater community, expose them to future careers, enhance their motivation, and increase their learning. By incorporating project-based learning and design-focused projects into the mathematics classroom, mathematics teachers can further develop future citizens who are able and willing to work together to devise innovative solutions to problems within and for the community.

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