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Building Engineering Interest and Sandcastles through Collaborative Instructional Design

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Abstract

A collaborative research project between students and faculty in the California Polytechnic State University College of Architecture & Environmental Design (CAED) and the School of Education was undertaken to bring motivation for design, engineering and construction careers into local elementary school classrooms. The project was initiated by faculty in the Architectural Engineering (ARCE) department of the CAED which includes departments in Architectural Engineering, Architecture, City & Regional Planning, Construction Management and Landscape Architecture. These departments can provide students and faculty proficient in the areas of building design and construction. Faculty and teacher candidates in the School of Education provide the knowledge and skills needed to introduce technical concepts and practices for the present and future education of elementary school students; thus creating rich fields for collaboration. Through a series of lessons fourth through sixth grade students learned and applied grade level appropriate knowledge and skills in the design and construction of two structures. A clearly defined process of roles required to build a bridge was first used to introduce design and construction concepts. This was followed by repeating the roles and steps through a less constrained process to design and build a sand sculpture. The culminating event was a contest held to build the sand sculptures. Pre- and post-assessments of students at the elementary school were conducted to investigate students' prior knowledge of the distinct work of the professions and if providing a practical application for math and science concepts enhanced student learning. Teacher candidates and cooperating teachers were surveyed to assess their familiarity with the professions, the application of science and math to the professions and their perceptions surrounding their students' abilities and interests. The paper describes the program, lessons learned and the assessment data.

Introduction

The Sandcastle Project was conceived as a means of introducing the design and construction professions (architects, engineers, contractors) into local elementary school classrooms with overall goals that were two-fold – 1) to provide elementary school teachers with real world examples of math and science to reinforce standard curricula and 2) to motivate interest in and relevance to math and science in elementary school students. This project was designed to address study results by the National Academy of Engineering[1] and President's Council of Advisors on Science and Technology (PCAST)[2], among others, which have identified the need to enhance the pathways to careers in science, technology, engineering and math to attract an abundant, diverse and proficient workforce. This involves both improving our educational content and conveying the importance, value and satisfaction that can be achieved in such careers. As the PCAST report emphasizes improving STEM education requires we "focus on preparation and inspiration." Further, "imprinting" engineering as a career pathway, as Ellis, Jackson and Wynn[3] have proposed, by introducing young students to engineers and connecting subject matter to relevant applications in engineering can support increasing student understanding of engineering in relation to the world around them, minimize misperceptions about engineering and highlight the many ways engineering improves the quality of our lives.

Engineering can motivate the need to master the principles and concepts presented in science and math and make them more accessible. This is a task best accomplished collaboratively by educators, industry and government each bringing resources and skills to reverse the decline of student interest and ability in science, technology, engineering and math.

Additionally, this project is designed to: 1) introduce 4th through 6th grade elementary students to the design process as a means of problem solving, 2) teach them to think about space and imagine how they can affect the built environment in which they live and 3) reinforce the importance of teamwork and collaboration by describing how they are used in the building design and construction process.

Program plan

The authors' work has explored a number of different methods for informing and engaging K-12 students in engineering. These have included using story and hands-on experiments in elementary grades[4], as well as more formal lessons to high school students including computer simulations of structural behavior. This outreach program was stimulated by the ideal location and situation of California Polytechnic State University in the San Luis Obispo community and was modeled, in part, on a similar program in the San Francisco Bay Area. Leap Arts in Education[5] sponsors an annual sandcastle contest which joins Bay Area art and design professionals with elementary school children in building sandcastles of the students' design. The beaches surrounding xx, multiple school districts with diverse populations, a polytechnic university well known for its hands on learning philosophy, and strong links between the university and the local professional community provide the optimal foundation for developing a similar contest on the Central Coast.

Initial program support was provided by a small university grant which encouraged collaboration across colleges as well as among departments within colleges. The authors chose to work with two faculty members in the School of Education who are teaching and mentoring candidates in the teacher credential program. The Sandcastle Project was envisioned in four parts: engineering content enrichment for teacher candidates, classroom lessons to introduce the design process and the professions involved in accomplishing a construction project to grades 4 through 6, an after-school program for interested 4th – 6th graders to undertake the sandcastle planning and design, and finally construction of the sandcastles at a local beach. The design of the program incorporates the six guidelines for improving K-12 engineering education and outreach presented by Douglas et al.[6] It employs hands-on learning, takes an interdisciplinary approach, addresses current math and science curriculum standards, engages teachers in the development of the lessons and enriches their understanding of content, provides mentors and role models who represent the diversity sought in the professions, and makes use of partnerships between multiple stakeholders.

The Sandcastle Project was jointly executed by three teacher candidates, two faculty from the School of Education and three students and two faculty from the CAED. Additionally, design and construction professionals in the community contributed time and financial resources to the project, especially the portion at the beach. CAED faculty employed their academic and professional perspectives on design and construction to educate the teacher candidates about these professions and to help develop content and lesson plans. The teacher candidates, already embedded in local elementary school classrooms, were in an ideal position to lead instruction supported by cooperating teachers and School of Education faculty. Further, a CAED student was partnered with each teacher candidate to support instruction and serve as a technical role model. This approach appropriately employed the skills of the students and faculty from both colleges. It also encouraged the professional development of the students of both colleges and linked the CAED students with local professional architects, engineers and contractors.

Program Execution

Each of the three teacher candidates worked in a classroom with a cooperating teacher at a different school. As shown in Tables 1 and 2 ethnicity and subject proficiency was broadly represented by the different schools. Teacher Candidate 1 worked in a split 4^{th}/5th classroom in School No. 1. Teacher Candidate 2 worked in a 6^{th} grade classroom in School No. 2 and Teacher Candidate 3 worked in a 5^{th} grade classroom in School No. 3. The teacher candidates and their cooperating teachers were given a pre-program survey to assess their teaching experience, their familiarity with the design and building professions, the application of science and math to the professions and their perceptions surrounding their students' abilities and interests. The survey was based on the work of Yasar, Baker, et al.[7] Teacher candidates were experiencing their first elementary school teaching and were all female. Cooperating teachers ranged in experience from 6 to 20 years teaching in elementary grades and were all male. Cooperating teachers and teacher candidates both expressed very limited familiarity with design, engineering and technology (DET) having not had courses in pre-service curriculum or continuing education. Both groups indicated they were moderately confident about integrating DET into their curriculum but stated their difficulty in doing so was based on their lack of training. All desired to teach students the underlying math and science supporting DET as well as its impact on society and felt it was important to incorporate engineering problems in math and science learning. Math and science were identified as the most important skills to engineering and cooperating teachers, more than teacher candidates, believed that engineers had relatively poor verbal and interpersonal skills.

Group	**School No. 1**	**School No. 2**	**School No. 3**
Hispanic or Latino	12%	79%	55%
White	77%	18%	40%
Socioeconomically disadvantaged	13%	91%	66%
English learners	5%	66%	31%

Table 1. 2012-2013 School Enrollment Demographics

CAED students were recruited through the college and departments. Ultimately the three students that pursued the program were from the Architectural Engineering department. In a series of meetings with faculty and students of the collaborating departments the teacher candidates were introduced to technical concepts and practices of the design and construction professions and to related applications of grade appropriate math and science. Math principles employed in the lessons included the calculation of slopes, areas and volumes, and applying scaling principles. CAED students were oriented to working with students and ways in which they could support the teachers; they also developed structural models and presentation materials for classroom use. The meetings were a two-way process with students and faculty sharing challenges and ideas for facilitating elementary student learning math and science concepts through design and construction, Figure 1 and Figure 2.

Group	English-Language Arts	Mathematics	Science
School No. 1			
All students	77%	82%	83%
Male	74%	86%	81%
Female	80%	78%	85%
Hispanic or Latino	54%	67%	-
White	53%	60%	85%
School No. 2			
All students	43%	61%	33%
Male	39%	61%	37%
Female	48%	62%	25%
Hispanic or Latino	39%	59%	31%
White	58%	68%	12%
School No. 3			
All students	61%	70%	47%
Male	60%	70%	50%
Female	61%	71%	45%
Hispanic or Latino	57%	69%	47%
White	63%	71%	50%

Table 2. 2012-2013 Standardized Testing and Reporting Results by School and Student Group of Students Scoring at Proficient or Advanced

Figure 1. Curriculum development by teacher candidates, CAED students and faculty.

Figure 2. Working through model building with teacher candidates.

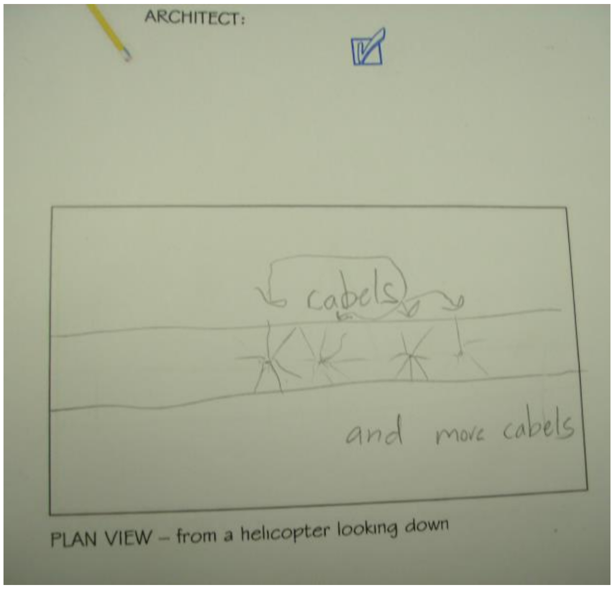
Prior to beginning classroom lessons teacher candidates administered a pre-survey to their students. Each class had between 21 and 31 students; a total of 76 students participated in the classroom activities. The survey, developed by the teacher candidates, reflected their desire to focus on a few math learning objectives in relation to the work of engineers. Pre-survey results showed that overall students could identify the tasks an engineer performs, but did not understand the tools they would use to do their work. About half of the students surveyed understood that to become an engineer one needed college education. Most students did not have a good understanding of proportion or what a scale drawing was.

With an understanding of the students' knowledge lessons were structured as 50 minute modules that strove to: 1) develop the elementary school students' awareness of bridges in their own physical environment, 2) introduce them to a vocabulary to describe bridges, 3) identify the design and construction process and the roles of different professionals, and 4) provide an activity in which the elementary school students could practice these roles and apply grade appropriate math concepts. The basis for the lessons was founded on work conducted by senior architectural engineering students at xx University.[8] The authors developed presentations on bridges and the roles of design professions for use by the teacher candidates and CAED students in the classroom. The activity involved the design and construction of a model bridge structure to meet specific user wants and needs. For the activity the elementary school students were formed into teams of 3 or 4 students. During the course of the design project each team sequentially took on the role of planner, architect, engineer and contractor. In this way the students incorporated writing, drawing and construction while expressing the perspectives of different disciplinary role players.

Figure 3. CAED student working with team.

As each team acted out the role of planner they described the goals of the bridge structure. Was it to be a pedestrian bridge, a bicycle bridge or a vehicle bridge? How wide and long must the bridge be? Upon completing a handout defining the bridge they wanted each team passed on the descriptions of the planner's requirements to another team, Figure 3.

Next each team took on the role of the architect. They had to determine what style of bridge was desired. Was it a beam bridge, an arch bridge or a suspension bridge? Given examples they were to draw plan and elevation views of the bridge design they had selected, Figures 4 and 5. These were then passed to another team. All teams next served the role of the engineer. They determined the scale of the model that was to be built based on the use of the bridge and a model bridge deck piece, Figures 6 and 7. They computed the area of the bridge and selected the materials required to construct the bridge. These specifications were then passed on. Each team then acted at the contractor/builder. Using only the plans and specifications provided they constructed the bridge from a kit of parts, Figures 8, 9, 10 and 11.



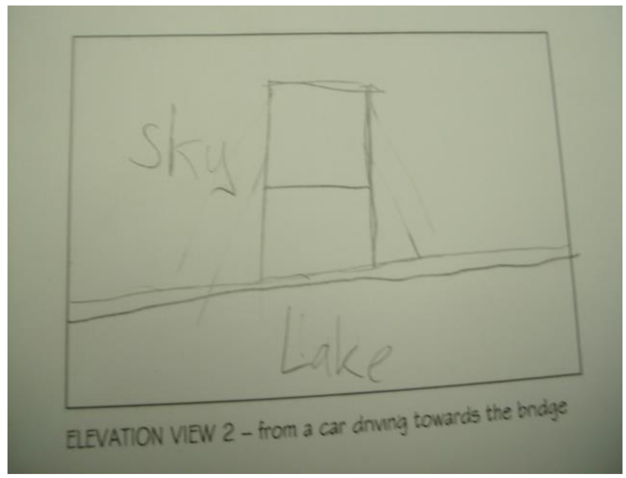


Figure 4. Plan view of bridge on worksheets.
Figure 5. Elevation view of bridge.

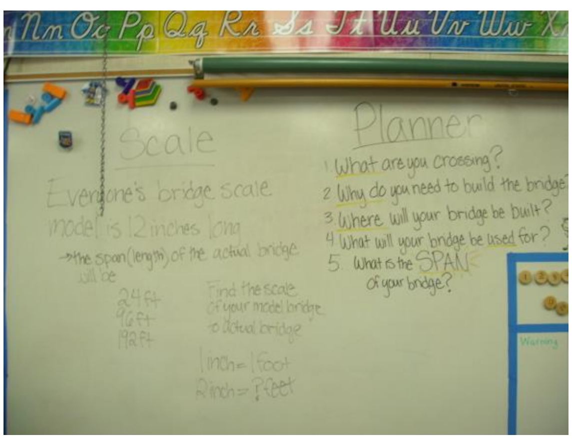


Figure 6. Determining the scale of the model bridges.

Figure 7. Teacher candidate and CAED student explaining the scale model.

Figure 8. Determining what additional building materials are needed.

Figure 9. Constructing a bridge according to the specifications.

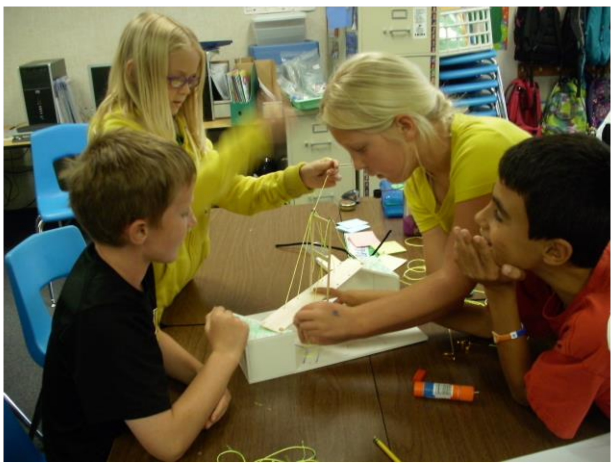


Figure 10. Completing the "suspension" bridge.

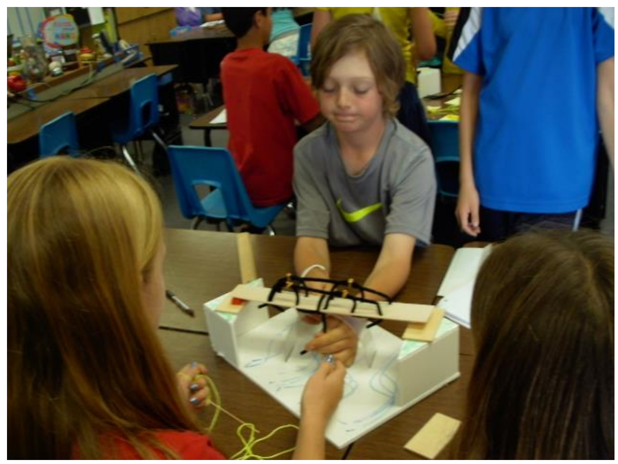


Figure 11. Completing the "beam" bridge.

Following the construction of all the bridge designs the students examined what was built from their initial specifications. Did the designs reflect what the planners and architects had envisioned? Did the construction reflect the drawings? Teachers and teacher candidates observed that students had difficulty giving up their original plans to other teams for completion. However, the students were resourceful in working to execute the desires of the designers with the materials at hand; railings were devised from available materials when they were shown on the drawings. When pieces did not fit as intended, students constructed solutions. They were proud of the products they produced in their teams.

To minimize time away from the standard curriculum it was initially hoped that the elementary school students would be encouraged to enroll in an after-school program and participate in the design and construction for the sandcastle competition. However, cooperating teachers and teacher candidates identified the opportunity to have all students engage in the learning during regular school hours as a break from standardized testing that was conducted over several weeks near the end of the school year. All students therefore participated in developing designs for the sandcastle competition. Using the theme of sea creatures, the elementary school students prepared scale models of designs for the sand sculpture in teams, Figure 12. They had to consider what forms were feasible, the tools they would need on the beach and the scale of the sculpture they could build as a class given the time allotted. Such an open-ended problem is more reflective of the design and planning activities undertaken by professional planners, architects, engineers and contractors. Addressing such questions through steps in a design process is a key feature of elementary engineering standards such as those by the Massachusetts Department of Education[9].

From the team designs developed each class voted to select one sand sculpture that they would build, Figure13. Teacher candidates and cooperating teachers organized parents to bring students to the beach site on a Saturday morning. Local design and construction firms were matched with each school to aid in building the students' design. CAED faculty and students transported shovels, pails and finishing tools to the site along with sandcastle competition t-shirts. The competition commenced at 9:00 am and concluded at noon. Elementary school principals, parents, and university faculty observed as teacher candidates, cooperating teachers and design and construction professionals assisted the students in bringing the sand sculpture designs to life, Figures 14, 15, 16 and 17. The event concluded with an award to each school and pizza for all.

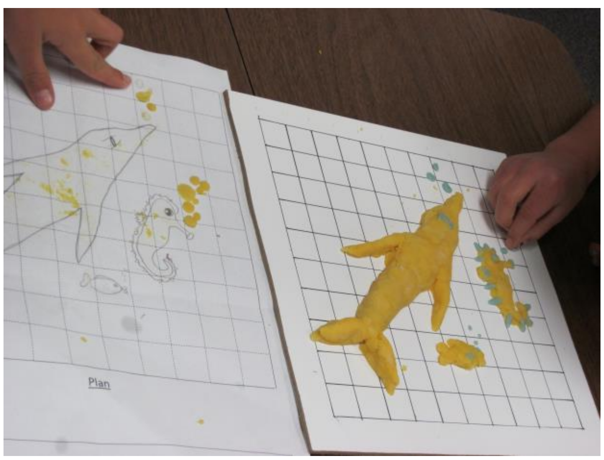


Figure 12. Sand sculpture team model.


Figure 13. Viewing team models.


Figure 14. Planning the sculpture construction.


Figure 15. From scale model to sand sculpture.

Figure 16. Putting the finishing touches on a sand crab.

Figure 17. Proud students, teacher candidate and design professionals of the dolphin.

Conclusions and Future Steps

Ultimately the program was principally funded by donations from local architecture, engineering and construction companies. Post assessment of the students indicated they had a better understanding of scale drawings and proportion. Most notably they learned that completing a project requires many steps and people of different skills. Teacher candidates and cooperating teachers expressed a heightened desire to understand design, engineering and technology to increase the relevancy of teaching math and science to their students. All in attendance expressed a desire to continue the project in the coming year. It is planned that more extensive pre and post assessments will be done to evaluate the effectiveness of the lessons and activities on the students' math and science learning. Additionally, the authors hope to continue working with the teacher candidates as they enter into full-time teaching positions and the cooperating teachers as they continue in their careers to assess their incorporation of DET in their teaching.

This project introduced elementary school students to the design and construction professions through a Sandcastle Project. Its goals were to stimulate creativity, an interest in building design, engineering and construction and to use real world examples of math and science to reinforce standard curricula. Based on the limited post-assessment of student and teacher participants the project successfully motivated students and developed skills in teamwork. California Polytechnic State University College of Architecture & Environmental Design (CAED) and the School of Education will continue to offer the Sandcastle Contest as a means of collaborating to bring university students into local elementary school classrooms. Future work includes expanding to more classrooms and improving links with the local design and construction community.

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