COMMON GROUND

The International Journal of Science, Mathematics and Technology Learning
Common Grounds Publishing, Champaign, IL, USA

Pre-Print

Please Reference Journal for Citation

Pedagogical Methods to Promote S.T.E.M. Literacy with Case-Study

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Abstract

There is a general employment demand in both academia and industry for students who are pursuing studies in a discipline that is part of the S.T.E.M. coalition: Science, Technology, Engineering, and Mathematics. However, such demands fail to attract students to S.T.E.M. careers as there is a high number of students who change academic paths away from an S.T.E.M. focused degree at higher-level institutions, while students at levels K-12 do not know that such S.T.E.M. professions exist. In this paper, a culturally relevant pedagogy is proposed for promoting Mathematics, Engineering, and Science literacy to students in grades K-12 and lower-level post-secondary students. This proposed teaching methodology aims to stimulate student interest in engineering, expose students to the social and academic skillset necessary to excel both academically and professionally in S.T.E.M. fields, and ultimately increase and retain student enrollment in academia within the S.T.E.M. disciplines. Additionally, a case-study exemplifying the effectiveness of this teaching paradigm is presented.

Keywords: Teaching Strategies, S.T.E.M., Program Development, Student Retention, Student Performance

Introduction

The S.T.E.M. cohort of Science, Technology, Engineering, and Mathematics has a vital role within the United States and globally, as these professions are the foundation on which technology, innovation, and research leading to advances in nearly all societal developments are rooted. It has been estimated that nearly 2.5 million jobs within the United States are available to hire students entering S.T.E.M. careers between 2004 and 2014, however many of these positions are outsourced to S.T.E.M. trained individuals outside of the United States because many of these positions cannot be filled by S.T.E.M. savvy American students or workers (Terrell 2007, 32-40; Manning et al. 2008, 35-54).

One of the main challenges facing American students who do not enroll in an S.T.E.M. degree field starts with the educational foundation on which students in the United States are taught. While it is generally perceived by most parents in the U.S. that children in grades K-12 are receiving a quality public-school based education, statistics reveal that the majority of American students are falling behind their international counterparts in reading, math, and science. These statistics reveal that America's top math student's rank 25th out of 30 countries when compared with students elsewhere in the world and that by the end of the 8th grade in middle school, U.S. students are two years behind in the math level being studied by their peers in other countries (Strong American Schools 2006, 277; Schmidt 2003). At the University level, only 233,000 bachelor degrees were awarded to U.S. citizens and residents constituting only 15.6% of overall degrees awarded nationally including all other disciplines (Burrelli 2010, 2-13). This is shockingly low when compared to countries like China, South Korea, and Germany which award S.T.E.M. bachelor degrees to 46.7, 37.8, and 28.1 percent of all bachelor degrees awarded in each country, respectively (Burrelli 2010, 2-35). Most of the public educational programs fail students in four ways. Primarily, math and science subjects are not emphasized because the public school system lacks the necessary personnel who can actively, accurately, and knowledgably teach S.T.E.M. subjects to prepare students with a basic understanding of mathematical and scientific concepts (Kuenzi 2008, 2-20). Second, students lack a basic comprehension and competency of mathematics and science impart because of such underexposure to S.T.E.M. fields. Third, students are expected to progress through the public education system which requires a gradual increase in complexity of Science, Math, and English concepts as the students mature and develop both mentally and physically, but students often fail to do so because they did not understand rudimentary concepts that were not implemented nor thoroughly taught at previous elementary levels. Fourth, if students do succeed by American standards, complete high school, contemplate pursuing a higher level degree in an S.T.E.M. discipline at a post-secondary institution; they are often competitively eliminated by international non-American students who test superiorly on standardized exams and fill academic programs in an S.T.E.M. field at the Graduate level. Additionally, these same non-American students present a mastery of math and science skills necessary to excel in S.T.E.M. academia when compared to American students of comparable demographics within the U.S.

Five-step Paradigm for Promoting STEM Literacy

Students who graduate with S.T.E.M. degrees and enter the S.T.E.M. workforce are expected to have a certain competency level necessary to be successful employees, which are ideally promoted by accreditation boards like the Accreditation Board for Engineering and Technology (ABET, 2012). But, a major problem with such idealized student outcomes fails to consider the culturally sensitive nature of education. The teaching paradigm proposed within this paper consists of a five step paradigm that should be used to promote S.T.E.M. literacy for grades K-12, which strengthens academic weaknesses which students may have, provides students the opportunity to learn ways to build the skillset necessary for a successful S.T.E.M. occupation through self-learning, and synergistically reinforces the expected ABET student outcomes. The teaching paradigm follows a sequential order listed from below:

1. Expose students to engineering concepts through projects using audio/visual media i.e. internet, books, videos.
2. Didactically lecture students about engineering/science/engineering theory through real-life applied problem-based learning.
3. Assign students an abstract, socially and culturally relevant group-based project requiring the students to utilize knowledge attained from the previous steps (lecture and research).
4. Student group presentations focusing on: a) why the project was developed, what is the need for the project, b) how does the design engineer a solution to the presented problem, c) what is the underlying theory as to how the model works (mathematical/scientific), d) what methodology was used to make the design
5. Students are academically tested for theoretical concepts, resolving problem-based concepts and engineering design through examination.

The expected outcomes for employing this five-step paradigm to promote STEM literacy will:

- Attract and bring awareness to students in grades K-12 about S.T.E.M. careers and how the relevancy of the field is incorporated within their everyday life.
- Build social teamwork, presentation skills and ability to articulate critical thinking skills which are necessary to excel in any academic discipline or career.
- Give students the knowledge to actively and confidently resolve engineering problems, and develop original solutions and designs.
- Retain student enrollment to attain S.T.E.M. degrees by fostering real-world socially relevant uses of engineered solutions and designs.

Step 1: Use of Audio/Visual Media to Introduce Engineering Concepts

Students of the 21st century use social media in nearly every aspect of their lives, and educational instruction methods used to teach 50 years ago are less than appealing to the students of today. Using social media teaching tools like the internet will allow students to develop research skills relevant to the 21st century, build independent critical thinking skills, build presentation skills, and captivate their attention to focus and generate interest in engineering theory. This is the first step of the teaching paradigm. When introducing concepts of engineering, the students are expected to use different forms of social media, mainly the internet, to gather information about the subject. For example, when introducing an engineering concept like Electricity and Magnetism (E & M), student would independently be expected to give a presentation on the subject and answer questions from both peers and the instructor focusing on the following areas of the concept:

- What is Electricity and Magnetism and what technology in our society uses such principles?
- What is a working example of E & M and how does it work?
- Explain the mathematical concepts of E & M

Students would then be evaluated based upon a customized instructor developed criteria checklist (Fig. 1). After students are evaluated using the performance list, each of the students' weaknesses can be easily identified because this task was an individualized student effort. This information is useful for the student as well, because it gives them feedback to weak areas of their skillset which need improvement. More so, it also allows the instructor to tailor classes/courses to the knowledgebase strength of the students.

Step 2: Didactic lecture to students about Engineering theory and applications through problems-based learning

Step two of this teaching model is the most traditional method used to teach students about S.T.E.M. concepts. This is a vital portion of the learning process, and one of the major problems hindering students today is that they are not actively engaged. Hence, it is a major component of teaching and learning needing revision. In this portion of learning, students should be introduced to concepts, and be given both homework assignments and in-class problems following in-class examples which clearly elucidate the subject theory. The key for student retention of the material is that the homework, in-class assignments, and problems should remain relevant to real-world applications. This would eliminate students feeling disconnected from traditional engineering problems which are the basis for most homework and examination problems that are derived from books with very ideal and non-practical themes. This is one of the major reasons students lose interest in pursuing S.T.E.M. education and possess the opinion that the knowledge and skills they are acquiring is not applicable to the real word.

Step 3: Abstract Project Assignments

The assignment of a project constitutes the third step of this model and is absolutely pivotal in the learning process. This is when students internalize what they have learned. It is also presented to students at the point when they begin considering the withdrawal from S.T.E.M. programs because they do not feel connected with what they are learning. This project prevents them from feeling overwhelmed by the complexity/volume of the material being taught. In this step, students are assigned a group based project which requires the use of knowledge gained through preliminary independent research about a subject/concept (Step 1) and the didactic lecture based system meant to give them the tools to engineer solutions (Step 2). Now, the goal for the student is to practically translate what they have learned by developing models and solutions to explain the theory learned and for them to engineer solutions to a given problem. For example, using the same concept of 'E & M' in the previous step, students would now work in groups to develop an applicable tool utilizing E & M theory to find a real world solution to a problem. An example of such a project would be 'Applications of E & M theory to develop a Power Generator'. The aim of this step of the paradigm is to give students the tools to develop something useful, ultimately targeting the development of their critical thinking skills. This is analogous to giving students the pieces to a puzzle, but letting them figure out how to put the pieces together to build something useful. It should be clear that no concise instruction or guidance should be given to the students. Rather students should work together as a team to resolve major issues, strategize a plan, and successfully complete the assigned task.

Step 4: Group Presentations Based upon Group Project

This is the fourth step of the learning model, which really serves as an evaluation tool for the concepts/subjects that the students have learned from the previous three steps. It allows for the students to work through the challenges that are inherent to working in groups as far as individual accountability for contribution towards the group progress, leadership roles, and adapting a complementary skillset to unify a team. Also, it gives students an opportunity to demonstrate how they have addressed their 'weak areas' identified by their instructor and peers during their individual presentations for preliminary research. Teamwork can be best evaluated using criteria in checklist in Figure. 2 (Lingard, 2010), as well as revising the individual performance checklist in Figure 1.

	Student Performance	Student 1	Student 2	Student 'n'…
1.	Did the student use different forms of media to explore subject /concept?			
2.	Did student openly express ideas during presentation?			
3.	Was articulation of ideas clear to audience?			
4.	Did student actively express an understanding of the subject? If no, what were their weaknesses?			
5.	Was their explanation of the subject/ concept scientifically/ mathematically correct?			
6.	What are suggested skillset improvements for student to focus on for subsequent projects?			
7.	Did student help others, or was helped by others? What suggestions can be made?			
8.	Can student discern between relevant and trivial topics?			
9.	Did student clearly and accurately address questions after the completion of the presentation?			
10.	Was student committed and engaged throughout the project?			

Figure 1. Student Performance Evaluation Form

During the group presentations, students should be able to articulate:

- What was the need for the project, and why the project was developed?
- What problems does the engineered solution solve?
- What is the principal theory of the design and how does the design work?
- What methods were used to build the design?
- Does the solution meet the restrictions of the project e.g. financial, design materials, etc.?
- Is this solution practical?
- What was learned, how they have completed the tasks, and what was the contribution of each member in the team?

After students are evaluated using both performance lists, students should have a sufficient understanding of what areas of their skillset need to be improved. Additionally, students should now fully possess an understanding of the material having been able to perform paper-based problem solving methods and by practically translating such theory to engineer real-world solutions and designs.

Teamwork Attributes Did the Team Member……	Member 1	Member 2	Member ‘n’….
1. Attend nearly all team meetings?			
2. Arrive on time for nearly all team meetings?			
3. Ever introduce a new idea?			
4. Ever openly express opinions?			
5. Communicate clearly with other team members?			
6. Share knowledge with others?			
7. Ever consider a suggestion from someone else?			
8. Ever adopt a suggestion from someone else?			
9. Generally tried to understand what other team members were saying?			
10. Ever help someone on the team?			
11. Ask for help from someone on the team?			
12. Generally complete individual assignments on time?			
13. Generally complete individual assignments with acceptable quality?			
14. Do a fair share of the work?			
15. Seem committed to team goals?			
16. Generally shows respect for other team members?			
17. Demonstrate an ability to do research and gather information?			
18. Shows an ability to distinguish between the important and the Trivial?			

Figure 2. Teamwork Evaluation Form (Lingard 2010, 20-23)

Step 5: Didactic Exam at the End of Module/Course

This fifth step of the paradigm is meant to return to the more traditional methods of teaching, which reinforce the students understanding of engineering theories and concepts. After, completing this phase of the process, students should be able to demonstrate a mastery of the engineering concept/theory. Based upon the results from the final examination, students and instructors are encouraged to have group discussions to discuss overall weaknesses and strengths which the students may have from ambiguity throughout the course or topical lecture(s). Students are then encouraged to make suggestions as to how improvements can be made in the presentation of the material so that an understanding of the subject/topic(s) is more clear. This highlights a key component of keeping teaching methodologies relevant to students. In all, such challenging and at times complex theories/problems should always portray obvious relevancy to students through real-world applications, while assignments and examination should actively engage students to enhance their comprehension of the educational materials.

Case-Study: Civil Engineering Bridge Building Project

The aim of this project was for students to conceptualize and build a bridge using wooden Popsicle sticks that could withstand a weight of at least 5 lbs and cross a distance of 7 inches. This project was taught using the 5-step teaching paradigm presented within this paper. The outcomes of this project substantiate the teaching methods presented in this paper, and ultimately increased student performance in group work as well as presentation and critical thinking skills. Additionally, this activity taught participants about engineering concepts, vocabulary, and mathematics through hands-on model building. Participants of this project included 36 students from Middle School (Level 8) and High School (Level 9, 10) who are members of the *I Have a Dream (I.H.A.D.) - Overtown* organization (Miami, FL, USA). *I Have A Dream – Overtown,* Inc. is a non-profit entity, which has been established to work with students in the Overtown community in Miami, FL. Overtown is a historic African-American community in Miami-Dade County, FL, USA. The mission of the *I Have a Dream- Overtown* organization is to help children from low-income areas become productive citizens by providing a long-term program of mentoring, tutoring, and enrichment, with an assured opportunity for higher education by providing full tuition to a public university or trade school upon high school graduation (*I Have a Dream-Overtown*, Inc., “About Us”, Accessed December 19, 2012, http://ihaveadream-overtown.org/about.html).

Preliminarily, students were asked to conceptualize what constitutes a ‘bridge’, and they were then asked to draw their thoughts on paper. Then an informal introductory conversion with students was conducted to determine what previous knowledge they possessed regarding the topic of ‘bridges’, the field of Civil Engineering, what they drew on paper reflecting those thoughts and the applications of bridges and the field of engineering in their everyday lives. Students were first given the task of drawing their thoughts so that their critical thinking skills could be used, and that their realizations after the discussions could not be reflected in their drawings. A rendition of a student’s drawing can be seen in Figure 3.

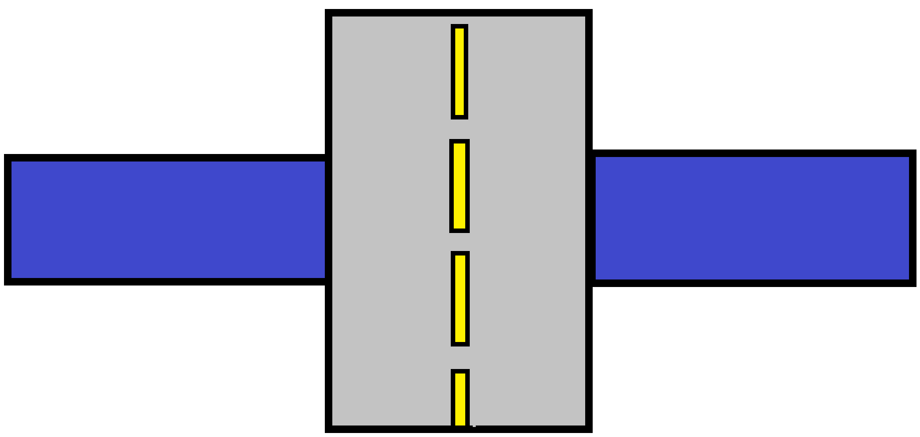

Figure 3. Reproduced illustration of a student’s interpretation of a bridge

Figure 3, illustrates a road bridge crossing a body of water. It can be seen that the students’ development of 3-dimensional spatial perspective is not well formed, as the drawing is in 2-dimensional form. The student also showed no understanding of how the structure of a bridge is developed, as the underside supporting structure of the bridge is not drawn. However, the student did draw the basic concept of a bridge, which is in its most basic form a structure or apparatus used to connect two separate regions or objects. Students were then assigned to pre-determined teams of 5-6 individuals, who showed varying degrees of understanding from the first task. It is understood, that by doing this, students with a greater understanding of the task will be able to help students who are uncertain about how to approach or achieve the goals of the project. Next, students were given time to 'self-learn' about bridges and the field using key terms that were discussed following the first activity and discussion. During this time, students were expected to prepare designs and drawings or blueprints for how they want to build their bridges. The instructor for the project then met with each group independently so that the students could demonstrate what they had learned. Individual contributions were noted, and then suggestions for research topics specific for each group depending on what they had presented were recommended. Also of importance was noting how tasks were designated for specific portions of the project. Once student teams were prepared and their designs were finalized, they were asked to present to their peers on what they envisioned their bridge would look like and how they would build it using the supplied materials of wooden Popsicle sticks, scissor's, and Elmer's glue.

Once students had commenced building their bridges, several unforeseen challenges were presented. In theory they had understood what they wanted to do, but it was very challenging translating their plans to physically build their bridge model. They were unsure how to use the tools they were given to obtain their end result. This problem highlights a current problem with today's curriculum in academia, in that the students become proficient at solving theoretical problems on paper, but fail to solve applied, on-site, or real life challenges. The practical experience gained by the students in building a model bridge, emphasizes a crucial step in the learning process which is to reinforce the skills and principles being promoted. Subsequently, students were then lectured to on relevant content and principles specific for this project. This phase of learning served to teach the students about specific vocabulary and terms used to describe what they are doing. For example, concepts like "force" and "load" were taught so that students could conceptualize free-body diagrams and how it relates to the object that they were building. Additionally, students were taught about basic structural mechanics and how angling the Popsicle sticks and cross-threading or weaving patterns affect the output structural strength.

Students were then given time to complete the construction of their bridges. This phase of learning truly reinforces the concept of teamwork. Several challenges which are common with teamwork were identified, such as team member contributions and complaints that some members are "not doing anything." This is a very common problem in team work, and such challenges lead to the emergence of team leaders who can control the group's progress, motivate each member to participate, and explain what, how, and why things need to be done. It is important that at this phase of learning that very little instructor intervention is made in order to maintain order and productivity of the group. When the students work through these problems with team members who show such lackluster attitude, they develop valuable life-learning skills that are nearly impossible to teach. Thus, exposure to these situations at an early stage is considered advantageous.

To conclude this project, students were not given a paper-based exam testing their knowledge of the subject as outlined in Step 5 of the learning paradigm. Due to the desired learning objectives, students were evaluated entirely on the functionality of their bridge design, and an end of the term group-presentation where they described their design, what they learned, and how and why their design failed. The bridge that each team built was tested for a maximum carrying load. Students learned that a design greatly influences the load parameter of measurement. One bridge built by a team accommodated a load of 145 lbs, which was the highest of all the teams (Fig.4A, 4B). This is particularly noteworthy, because this design was conceptualized and built by a single student whose team had abandoned the project mid-way through the assignment.

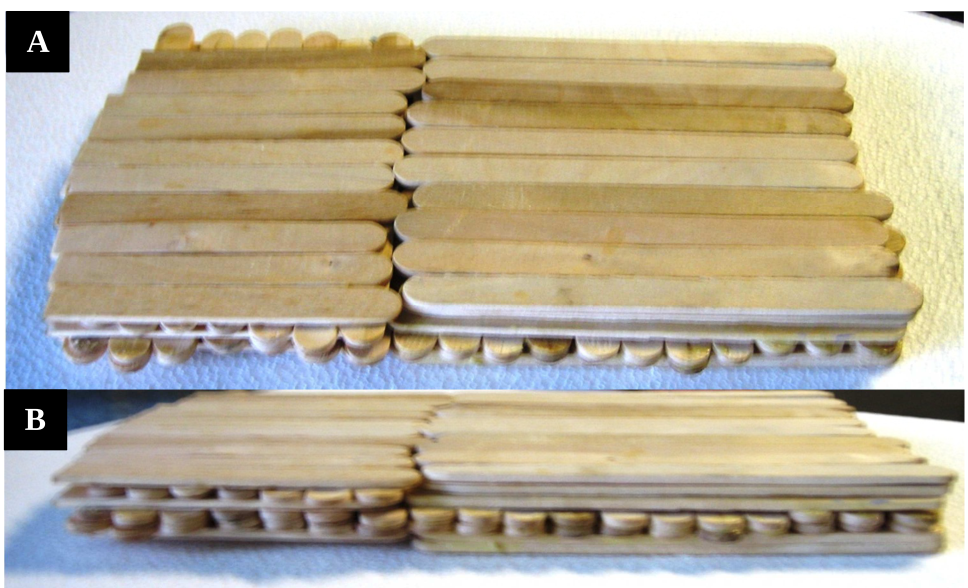

Figure 4. Student bridge that accommodated a 145 lb. load.
Top view of bridge, B) Side view of bridge showing alternating 0˚ & 90˚ plies.

In this design, the student applied a simple but very efficient principle to improve the strength of their bridge that was taught during the didactic lecture. To increase the strength of the bridge's platform, they alternated plies or layers of their platform at 0˚ and 90˚ orientations (Fig. 4B). They essentially stacked each ply, which greatly reinforced the load capacity of the structure. The student's application of this theory, exemplified the effectiveness of this 5-step teaching model, because they created an effective design within the restricted parameters, worked through internal team challenges, applied learned concepts from lectures, and articulated their design and outcomes to the class.

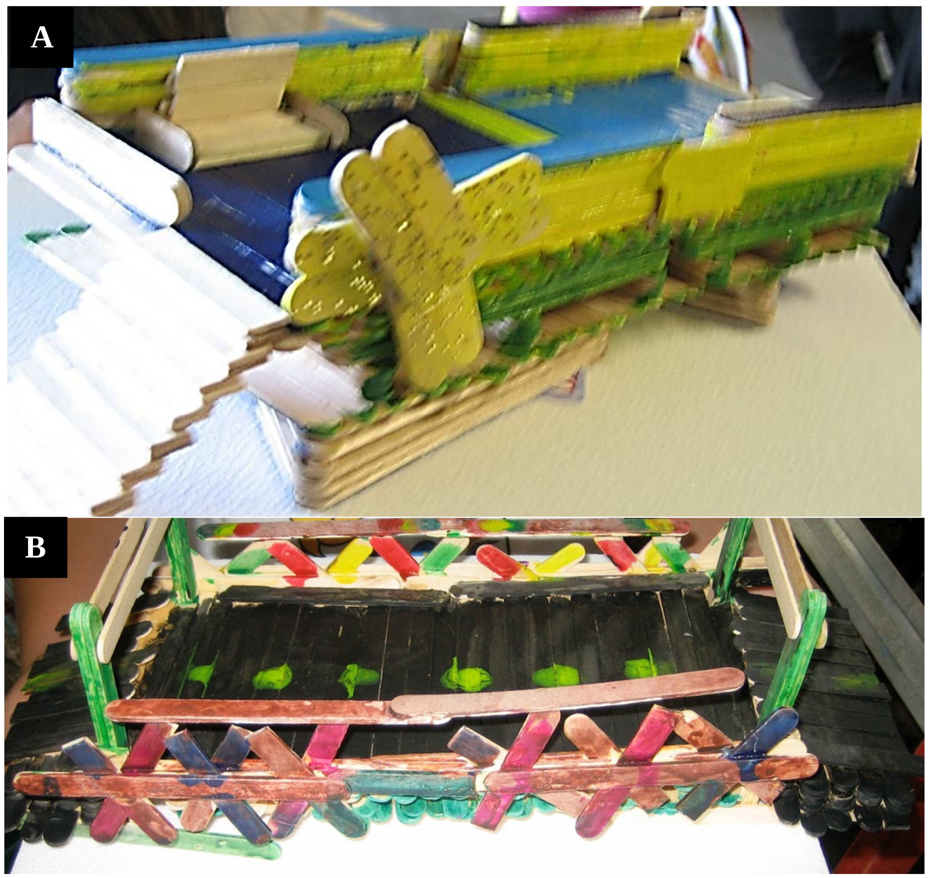

Figure 5. Architecturally designed bridges made by two different student teams

Other student bridge designs can be seen in Figures 5A & 5B, which show how much the students learned after the 5-step learning process. In these designs, the students extend the design of a basic bridge to be more artistic. From this experience, students learned that the most artistic design is also not always the most effective or efficient. Figures four and five highlight what the students have learned through their incorporation of terraces, benches, ramps, rails, colors, and structural support in their designs which was not evident when the project began (Fig. 3).

The employed 5-step teaching model presented in this paper captivated student interest that would have otherwise been lost if taught following a traditional means of teaching through lectures and textbook problems. In this project, students were given tools, criteria for a project, and the freedom to explore and self-learn while being supplemented with more traditionally didactic lectures. As seen before the project began (Fig. 3), students showed little to no understanding of structural designs for a bridge. However, as seen in Figures 4 & 5, students applied engineering concepts to strengthen their bridge designs and structural components to increase architectural appeal that were not previously considered. Furthermore, students developed quality skills of working as a team, and vital presentation skills that are necessary to articulate their thoughts, opinions, and questions regarding course content and project outcomes.

Conclusions

It is important for educational teaching methodologies to evolve to attract students who are future S.T.E.M. professionals and to advance the S.T.E.M. field itself. Employing archaic teaching methodologies in a modern era of learning and technology often leaves students disinterested in the material, the profession, and the desire to complete a post-secondary degree in an S.T.E.M. field. In this paper, a five-step pedagogical method for promoting S.T.E.M. literacy has been introduced as a pragmatic paradigm aimed to attract and bring awareness to students in grades K-12 about the S.T.E.M. coalition of fields. This is achieved in a number of ways by building social teamwork and presentation skills necessary to excel in any employment discipline (particularly S.T.E.M.), give students the knowledge to actively and confidently resolve engineering problems, innovatively derive solutions and designs, and most importantly maintain enrollment to attain an S.T.E.M. degree by fostering real-world socially relevant applications of the material being taught. Although the efficiency of both instructors and students will determine the measured success of using this model; employing this paradigm has been shown to significantly improve promoting S.T.E.M. literacy to students with respect to comprehension of S.T.E.M. themes, recruiting students in grades K-12 to S.T.E.M. fields, and retaining students to complete a post-secondary degree in an S.T.E.M. discipline.

Acknowledgements

Dharam Persaud-Sharma is supported by NIH Fellowship number NIH/NIGMS R25 GM061347. I, D.P.S. would like to thank the Buchbinder family (sponsors of the I.H.A.D.- Overtown Inc.) and the ‘Dreamers’ who have allowed me to be a part of their lives for the past few years as a voluntary mentor/instructor. You all motivate me to continue working to be the difference that I want to see in the world.

I am all that I have met.
~ Alfred Tennyson

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