

Integrating Engineering Design Process in K-12 Curriculum in Virginia with Project-Based Learning

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Abstract

Global competitiveness and lackluster performance of US students in STEM areas has forced the educational community to take a fresh look at the STEM curriculum in K-12 programs. Federal government agencies like the Department of Education and National Science Foundation have funded many programs for improving STEM education. However, the engineering part of STEM is often neglected. The engineering design process is an integral part of the STEM “E.” Lack of student interest in technical and engineering careers can also be attributed to the lack of an integrated approach in teaching math, science, technology, and engineering. To engage students’ interest in a technical career path, it is important that they can establish a link between theoretical knowledge and its application to solve real-life problems early in their learning experience. Project-based activities have a proven record as an instructional tool. The effectiveness of such activities as a pedagogical tool has been supported by research in the acquisition and retention of knowledge.

Introduction

With the VA STEM CoNNECT project funded by the state Department of Education, Virginia has attempted to address the integration of the design process by developing project-based learning kits and associated instructional modules to engage K-12 students in engineering tracks. Five marine kits and associated instructional modules were developed

under the grant to incorporate the engineering design process at the middle school level. The teacher training component of the project has provided training in using and implementing these modules. This paper presents the motivation behind developing these project-based learning (PBL) modules, issues related to implementation and results from teacher workshops. The goal is to create a long-term pipeline of students into the educational pathways leading to engineering and engineering technology degrees.

Project-Based Learning as a Teaching Tool

Project-based learning has a proven record as a teaching tool. The constructivist learning theory suggests that people learn better by actively participating in the learning process [1]. To involve students in the participatory learning process, the interaction among students as well as between students and the instructor in a classroom becomes critical.

Educators have been designing, using, evaluating, and writing about project-based learning (PBL) for more than 20 years; however, it has not found widespread acceptance in classrooms. PBL is a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions, and carefully designed products and tasks [2]. PBL is ideal for connecting factual knowledge, principles, and skills to their application within a profession [3].

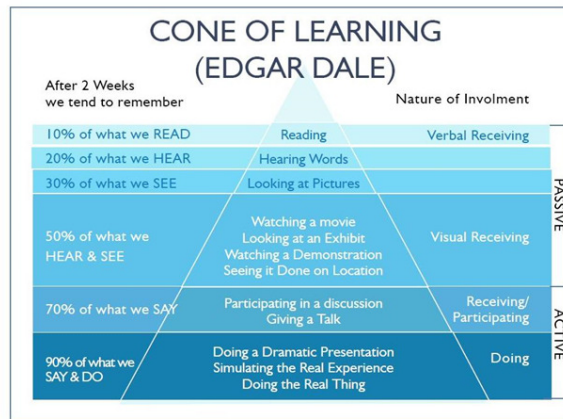


Figure 1. Edgar Dale’s cone of learning [4]

Goals of the VA STEM CoNECT Project

The VA STEM CoNECT project was designed to address the knowledge gap that exists among K-12 educators about importance of engineering, E in STEM, and to emphasize the fact that integrated STEM education is critical for engaging K-12 students in STEM fields. The primary goals of the project are to develop and implement a vertically aligned K-12 STEM curriculum and deliver a teacher professional development program that integrates the engineering design process into the mathematics and science curriculum. Ten institutions of higher education participated in this statewide effort for enhancing STEM education with various institutions selecting to focus on elementary, middle, and high schools. Old

Dominion University, along with Virginia Tech, focused on the middle school. ODU selected the motor lifeboat (MLB) design activity as an exemplar and developed the curriculum around this activity. The program also provided ongoing school-year support through EDMODO.

VA STEM CoNECT Project—Overview and Schedule

The curriculum was carefully designed to gradually build the knowledgebase of participants, starting with concept activities and PBL kits and leading to the engineering design process. The curriculum model is shown in Figure 3. The content of the workshop was carefully designed to introduce the participants to the engineering design process and how to

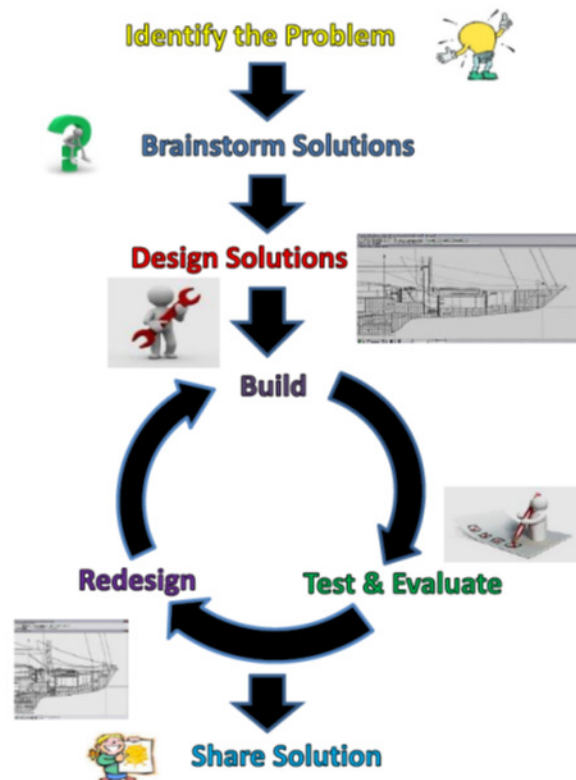


Figure 2. Engineering design process, simplified

incorporate this process into classroom activities using the project-based learning kits provided to teachers after the workshop. The schedule of the workshop is shown in Table 1. During Day 1, participants were introduced to “STEM: E is for Engineering” and then a “What Do Engineers Do?” session. This was followed by a panel discussion with participants from the ship-building industry. During the afternoon, participants visited Colonna’s Shipyard. Day 2 sessions started career education and exploration, where teachers explored various techniques for expanding students’ STEM career awareness. This was followed by a hands-on activity session including Marine Kit 1: boat design and concept activities on density, buoyancy, mass, resistance, and kinetic energy. Day 3 started with a panel session of

five industry speakers who talked about educational pathways to become an engineer and their experiences. After this, participants were introduced to Marine Kit 3, ship stability, and Marine Kit 5, hull design, followed by an introduction to the engineering design process. Day 4 was devoted to Marine Kit 7, propulsion, and a group activity leading to the boat design. Participants used the engineering design process to create a motor lifeboat for rescuing people stranded on an island due to a hurricane. Each team worked with a faculty mentor to develop an innovative design; then they built the boat and tested it in a tank. All four teams recorded the time of travel of the boat, and the boat with the best hull design won the competition. Day 5 was devoted to the development of an exemplar and lesson plans by teachers working in groups. Teachers were shown the project website and how to upload their lesson plans to Moodle.

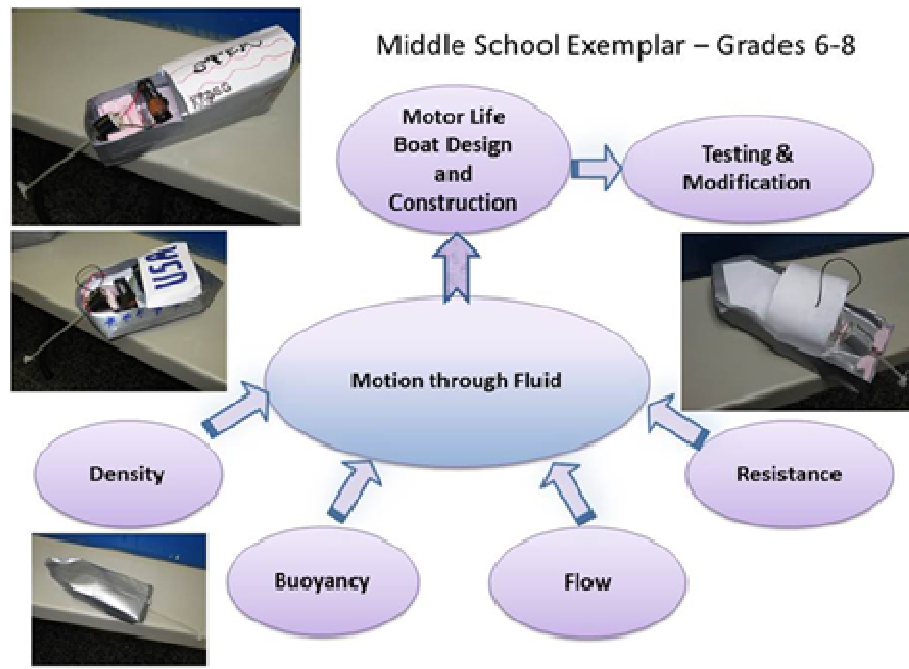


Figure 3. Middle school exemplar and MLB design models

Teacher Training

A total of 40 middle school math, science, and career education teacher participants were selected for the study, along with 40 in control group. Teachers were selected from two participating public school systems, Portsmouth and Suffolk. The teacher training component included a one-week summer workshop for the participants with instructional modules taught by ODU engineering faculty, a shipyard tour, concept activities, industry panels, a team design activity, exemplar development, and reflections. The control group did not receive the summer training; however, they filled out surveys and provided feedback.

Summer Workshop Sessions

The summer workshop curriculum for teachers (Table 1) was designed to first introduce participants to the engineering discipline and the educational pathways to get there. On Day 1 of the workshop, participants were taken on a tour of a working shipyard and presented the design problem, which formed the basis of the MLB design exemplar. Day 2 began with career exploration, physical simulation of yard operations using Marine Kit 1, and concept activities on scientific principles underlying the design of boats: buoyancy, density, salinity, mass, volume, and kinetic energy. Day 3 began with an industry panel discussion on becoming an engineer followed by the hull design module and boat design activity.

Table 1. VA STEM CoNNECT summer workshop schedule, 2013

VA STEM CoNNECT SUMMER WORKSHOP SCHEDULE - 2013					
	5-Aug	6-Aug	7-Aug	8-Aug	9-Aug
SESSION I	09:00 - 10:00 Welcome, Overview, Pretest (Verma)	09:00 - 10:30 Team Activity: Career Exploration for Middle School Teachers (Brown) (to be held in Education Bldg.)	09:00 - 10:30 Becoming an Engineer: Skills and Education (ACEC presentation and panel)	09:00 - 10:30 Team Activity Marine Kit 7, Propulsion (Selby)	09:00 - 10:30 : Work in teams to develop draft exemplars
	10:00 - 10:30 STEM: E is for Engineering (Selby)				
<i>10:30 - 10:45 BREAK</i>					
SESSION II	10:45-11:00 EDMODO Overview (Lawrence & Eller)	10:45 - 11:05 SE Model (Verma, Eller)	10:45 - 12:00 Team Activity, Model Exemplars: Marine Kit 3- Boat Stability (Verma, Luetke)	10:45 - 12:00 Team Activity: Boat Design: Problem Identification, Brainstorming, Design and Prototype (Build) (Verma, Selby, Luetke)	10:45 - 12:00 Work in teams to develop draft exemplars
	11:00 - 12:00 What Do Engineers Do? (Presentation - Verma, Luetke)	11:05 - 12:00 Team Activity: Model Exemplars: Marine Kit 1- Boat Design (Verma, Luetke)			
	12:00-12:20 Design Problem Overview (Verma, Eller)	<i>12:00 - 01:00 LUNCH</i>			
	<i>12:00-12:30 LUNCH</i>				
SESSION III	01:00 - 03:30 Colonna's Shipyard Inc.Tour (ODU Bus to transport participants to Colonnas)	01:00 - 01:30 Engineering Design Process (Selby)	01:00 - 02:30 Team Activity, Model Exemplars (Marine Kit 5- Hull Design) (Verma, Luetke)	01:00 - 3:15 Team Activity Boat Design: Test & Evaluate, Redesign, Share Solutions (Verma, Selby, Luetke)	01:00 - 02:15 Share and critique exemplars
SESSION IV		01:30 - 03:15 Concept Activities: Area, Buoyancy, Effect of Salinity/Density, Volume/Mass, Kinetic Energy (Verma, Luetke, Eller)	2:30 - 3:15 Boat Design Activity using the Engineering Design Process (Verma)		02:15 - 02:45 Next Steps, Assignments (Verma)
<i>03:15 - 03:30 BREAK</i>					
CLOSING	3:30 - 4:00 Travel Time	03:30 - 04:00 Reflections and Assignments	03:30 - 04:00 Reflections and Assignments	03:30 - 04:00 Reflections and Assignments	03:30 - 04:00 Reflections and Assignments

Day 4 started with the propulsion module, and the participants continued the boat design activity, testing and redesign. The last day of workshop was devoted to help and guide participants develop their own exemplars and associated lesson plans. A brief description of each session is presented below.

STEM: E is for Engineering: This session presented the importance of engineering in STEM.

What Do Engineers Do: Participants interacted with engineers from industry to learn about their daily life and work.

Design Problem Overview: Dr. Verma gave a quick overview of the design problem facing the participants: designing a MLB to rescue people stranded on Tangiers Island due to Hurricane Samantha (Figure 4).

Colonas Shipyard Tour: Teachers visited the Colonas Shipyard (Figure 5), a family-owned business in Norfolk, and received a tour of the yard along with a demonstration of the large boat carrier. In addition, they visited various machine shops to learn about the processes used to build a boat.



Figure 4. Boat design by Dr. Verma



Figure 5. Colonas Shipyard tour

Career Exploration: Dr. Brown explored various career STEM careers in science and engineering with the participants.

Marine Kit 1 Shipyard Operation Activity: This activity simulates operations within a shipyard. Plasma cutting, bending, and welding shops are simulated. Participants used card stock paper to build a container ship. This simulation demonstrates modular construction of a ship.

Engineering Design Process: This session provided a review of the engineering design process and how it is used to design, build and test products.

Becoming an Engineer: This session was designed to teach participants about educational pathways needed to become an engineer.

Marine Kit 3, Ship Stability: This endeavor involves the understanding of the center of gravity, center of buoyancy, and Archimedes' Principle. This simulation uses a foam hull shape to conduct experiments to identify the center of buoyancy and observe the effect of salinity on buoyancy. See Figure 6.



Figure 6. Marine kit activity

Marine Kit 5, Hull Design: Participants learned about various types of hulls used in boat construction and their application.

Marine Kit 7, Propulsion: Dr. Selby conducted this session. See Figure 7.

Boat Design Activity Using Engineering Design Process: During this session, participants worked in teams of 5 to design and build an MLB for a rescue operation (Figure 8).

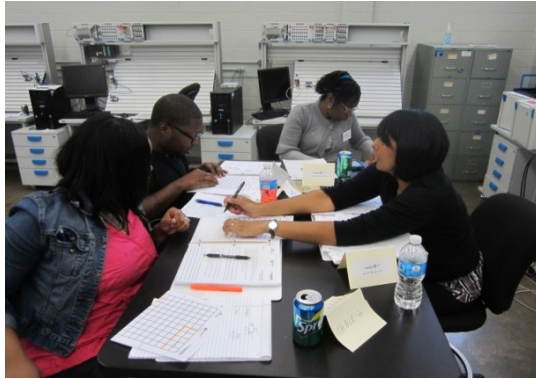


Figure 7. Concept activity on area and ship stability, marine kits



Figure 8. Boat testing and boat design

Participants Evaluations from Summer Workshop 2013

After the workshop, teachers were asked to give their opinion on the quality of presentations, hands-on activities, tours, and overall sessions in the summer workshop. Figures 9 and 10 present the bar charts of participant's evaluation for each session. The score varies from 5 as excellent to 1 as poor. Scores for all sessions ranged between 4.18 and 4.9, indicating overwhelming satisfaction with the content and quality of the summer workshop.

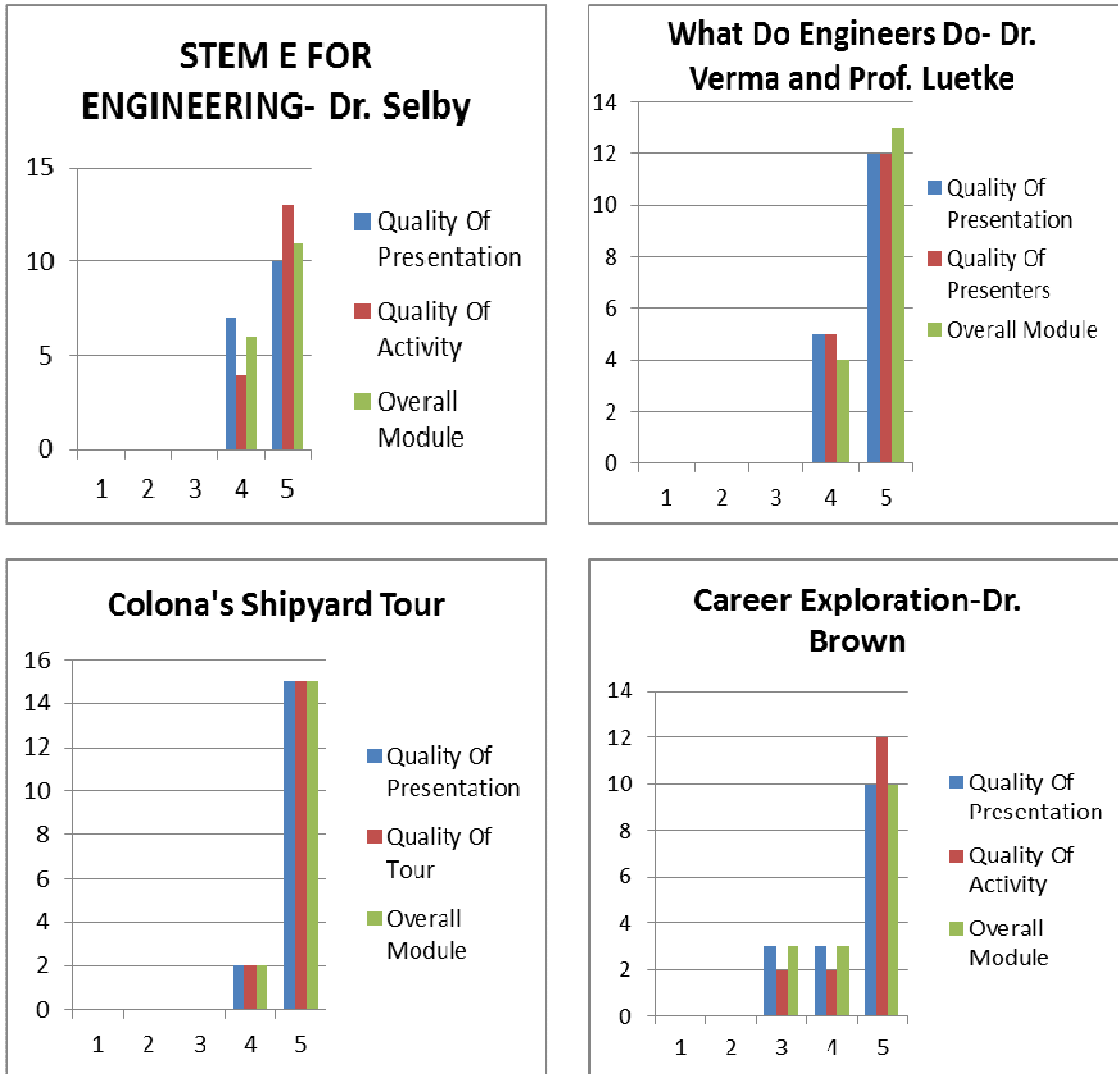


Figure 9. Participants' evaluations from summer workshop 2013

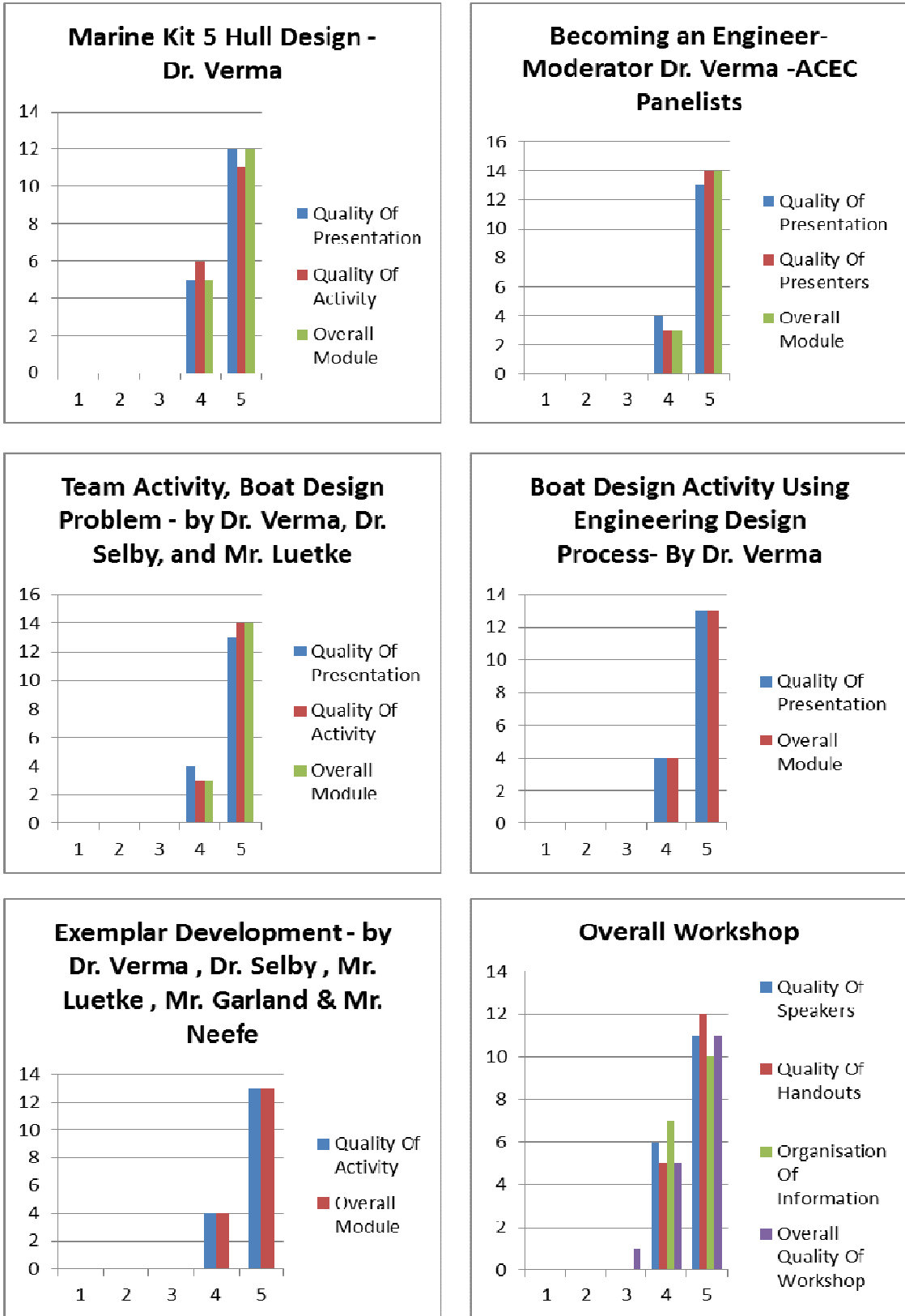


Figure 10. Participants' evaluations from summer workshop 2013

Conclusions

The VA STEM CoNNECT project has successfully developed and integrated project-based learning activities within the middle and high school curriculum. The marine kit activities and the instructional modules complement the standards of learning for middle and high schools. The project demonstrates that learning about ship design, construction, ship operations, and ship stability concepts are made easier by incorporating project-based learning activities within the curriculum. Student learning is enhanced by incorporating these activities, where students work in groups to accomplish problem solving. Open-ended problems provide opportunities for group discussion and creative thinking. Students' comments from course evaluations indicate that students find these learning experiences very enjoyable. Participating teachers believed that the activities were well designed and will engage students in the classroom. Widespread use of marine kits and the associated instructional modules will successfully engage students and attract them towards STEM-based careers in the marine industry.

Acknowledgments

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Biographies

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