122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11490

Project-based learning in a high school pre-engineering program: Findings on student achievement (RTP, Strand 3)

Todd France, University of Colorado Boulder

Todd France is a Ph.D. candidate at the University of Colorado Boulder. He is part of the Graduate STEM Fellows in K-12 Education Program and helps teach and develop curriculum at a high school STEM academy. His research focuses on pre-engineering education and project-based learning.

Project-based learning in a high school pre-engineering program: Findings on student achievement (K-12 & Pre-College Engineering, RTP, Strand 3)

The STEM academy

In the fall of 2009, a pre-engineering academy within a newly-renovated public high school opened its doors. Though the program officially carried the label of STEM, the primary focus was set squarely on the 'E'. The overarching goals of the academy were to introduce students to the field of engineering, providing them with positive experiences in the field, as well as to help prepare them for entering an engineering or STEM-related degree program upon graduation. At the same time, there was a noted purpose to remain inclusive, to serve the local community and the general population of the school, more than half of which was made up of underrepresented minorities. By 2013, the once-dire school's previously-declining enrollment had turned around, due in large part to the STEM initiative. About one in four students at the school was enrolled in the academy, which boasted a total of 340 members. The academy was quite diverse, minority and female students each comprising 35% of the population, while 23% were of low socio-economic status.

Lacking the necessary funds to purchase ready-made engineering curricula at its inception, two science teachers had been tasked with creating the course plans themselves. These two, who also served as the original instructors, possessed valuable backgrounds – one having earned a degree in mechanical engineering while the other had worked in the construction field. Although neither had experience in engineering education methods, faculty members from a nearby engineering college provided guidance. Before designing individual courses, the teachers generated two documents intended to form the foundation of all ensuring coursework. The first of these documents, entitled the Academic Standards, focused on five key areas for student development: 1) STEM career exploration, 2) collaborative teamwork skills, 3) STEM skills and knowledge, 4) open-ended hands-on design, and 5) communication skills. The second, called the Grade Level Expectations, broadly outlined the learning outcomes for each of the program's four years. These expectations dealt largely with the utilization of the engineering design process, computer-aided design, physical construction, technical report writing, and experimental data collection. For example, sophomores' expectations included the ability to "use provided STEM related content and resources to complete the required project," while juniors were required to be "aware of, and independently seek, STEM related resources to complete projects and assist with design needs."

The college representatives recommended that the academy employ the project-based learning model. Not only would hands-on projects engage students in the classroom, much of the coursework could be completed in teams, allowing the students to gain valuable collaboration experience, a key skill the faculty members noted that their own incoming college freshmen were lacking. The engineering design process was established as the means by which students were expected to work through their projects, intended to foster critical thinking as teams proceeded through iterative cycles of ideation, creation, evaluation, and modification aimed at optimizing product performance. Rather than relying on traditional written assessments, students were to be largely evaluated by authentic methods, primarily the performance of their physical products as well as the quality by which they communicated their findings.

Literature review

A plethora of twenty-first century careers, including those which do not yet exist, require higher-order thinking skills, and professionals with abilities to apply knowledge in a constructive manner are becoming increasingly valuable in our ever-changing world.[1,2] Students, therefore, must be expected to develop sharp critical thinking skills, defined as the ability to reason, make judgments and decisions, and problem solve.[3] Employing this high-level cognitive process allows for hypotheses to be established, arguments to be examined, evidence to be weighed, and defensible conclusions to be declared.[4] Such practices are important for many careers, but are indispensable for engineers.

In order for students to develop these qualities, there must be a clear communication of learning goals[5] – the knowledge they are expected to know, the skills they are expected to do, and the habits they are expected to possess.[6] In engineering, learning goals can be categorized into four broad areas: factual knowledge, conceptual understanding, skills (communication and procedural), and habits-of-mind.[7]

To foster engagement, schools are turning to active learning methods that stress dynamic student involvement in classroom lessons and activities. Research supportive of active learning points to increased levels of higher-order thinking, long-term information retention, and intrinsic motivation.[8,9] Strengths of the interactive model are attributed to the hands-on application of newly-attained information, more likely to be integrated within learners' knowledge bases and skill-sets. One sect of this instructional style, project-based learning, is backed by similar research, in particular, an increase in problem-solving abilities, as well as gains in collaborative skills.[10,11]

But this stance is not unanimous.[12,13,14] Due to the vast amounts of relative freedom afforded in such classrooms environments, a degree of self-regulation – the manner in which students are capable of monitoring and controlling their own thinking, motivation, and behavior – is necessary.[15] Expert learners, those who possess high self-regulatory capabilities are thus well-suited to project-based learning.[13] Conversely, inexperienced learners who lack self-monitoring skills often experience difficulties in student-directed situations which require them to initiate inquiry, direct investigations, manage time, and use technology productively.

Furthermore, capturing the benefits of an inquiry learning model necessitates a foundation of factual knowledge.[1] A strong knowledge base helps students flexibly retrieve information with little effort, providing cognitive capacity to organize thoughts, interpret observations, connect concepts from other disciplines, reason, problem solve, and develop explanations.[16,17] In engineering design courses, whereby an iterative cycle is embedded into the process (sometimes referred to as trial-and-error), it is imperative that students apply this tactic mindfully.[18] Such mindfulness calls for detailed observations and logical reasoning – ideally, in concert with requisite math and science content – followed by design modifications to address noted issues. On the opposing end of the spectrum, those with severely limited knowledge bases may not best be served by an instructional approach requiring self-directed inquiry.[19] If students are forced into situations for which they are unprepared, cognitive overload may consequently result, negatively affecting their learning.[20] For these types of learners, traditional direct instruction may be favorable.

Even for well-prepared students, project-based methods can be inefficient. Investigations of ill-defined questions, a hallmark of the model, can easily go off track as students pursue peripheral, fruitless ideas.[13] Likewise, because learning in such an environment must be viewed as idiosyncratic – that is, students not only search for effective solutions down a myriad of pathways, but may also comprehend observations entirely unique from one another – students may not encounter and construct the "right" knowledge, as intended by the learning goals.[21]

Though strong curricula in STEM fields should have a concentrated focus to provide students the opportunity to master key topics,[22] project-based courses often require students to apply a broad spectrum of knowledge. Again, due to the open-endedness of the project-based learning model, there is little assurance students will encounter essential content. As such, students in these classrooms may have a less rigorous understanding of underlying fundamentals.[10]

One drawback of project-based learning is that hands-on activities are not automatically "minds-on."[17] Oftentimes, the focus of activities becomes object manipulation rather than knowledge attainment and skill development. This separation between activities and content can be perpetuated by teachers who routinely emphasize the task to be completed rather than the material to be learned, a common mistake.[23]

An intertwining of content and projects must therefore occur if the aim of product design is to employ disciplinary practices. Ideally, successful products will demonstrate achievement, providing indicators of learning through authentic assessment measures. But like all assessments, it is necessary for educators to take the following questions into account when creating assessments, as a litmus test of sorts:[24]

1. Could students do the proposed assessment well but not really have mastered or understood the content in question?
2. Could students do poorly on the specific assessment but really have mastery of the content in question?

The effectiveness of projects can be strengthened by posing questions which students perceive as worthy of investigation, then highlighting the specific knowledge and skills required to generate successful solutions.[13] If content and project connections are not explicit, coursework can be viewed as irrelevant, commonly resulting in disinterest. However, students may seek to find solutions without applying intended content. A study of high school students enrolled in the nationally-recognized high school engineering programs Project Lead the Way and EPICS High, for example, found that students commonly failed to utilize math strategies while problem solving.[25] Said one teacher in the study, ". . . if they can find way to solve the problem without the math . . . they will."

Traditional engineering education at the college level has emphasized knowledge transmission from instructor to student in a passive classroom setting.[26] In programs with a design focus, there is commonly a 'basics first' approach in which foundational concepts are initially taught by lecture, followed by design tasks in the latter stages of the program.[27] But this deductive approach – moving from generalities (principles and theories) to specifics (application) – has several flaws, not the least of which is the general belief that people typically learn inductively, applying knowledge they have acquired in specific contexts and generalizing to broader scales.[28,29] Design-based activities not only provide opportunities for students to learn inductively, they can be leveraged as a motivational tool for students to learn foundational skills and content, taking full advantage of the field's potential for engaging students.

The preferred classroom environment presents situations resembling professional workplace conditions,[30] an end goal being to foster students' abilities to conduct 'full' or 'disciplined' inquiry, characterized as the practice of investigating, designing, implementing, and evaluating one's own work in the same manner as professionals.[31,1] Of course, achieving full inquiry at the high school level, however, should not be expected since students lack the knowledge bases, procedural skills, and motivation of professional engineers.[25] There must be a recognition of distinction between the behaviors of experts and novices, and rather than mirroring professional work, students should be expected to practice 'adaptive' inquiry, which involves the relationship between the knowledge and abilities a student brings to the classroom and a teacher's capacity to flexibly shape lessons and activities in response to the student's needs.[19]

Teachers must still strive to adapt aspects of authenticity into the classroom.[19] A major point of frustration, for both students and instructors, is identifying an appropriate amount of guidance, which must be tailored to each student's capabilities.[32] If students are not provided enough direct instruction during the inquiry process, they may flounder in a state of 'unguided discovery' by expending excessive amounts of time exploring unproductive ideas.[13] Under these circumstances, confusion may lead to frustration or may metastasize into misconceptions, and, due to frequent false starts, learning can be quite inefficient.[33] Students should not be expected to naturally possess quality investigative skills, and inquiry must be viewed as a process to be learned, not a silver bullet for learning content.[34]

However, offering excessive guidance can interfere with students' processes of knowledge construction and problem solving. Rather than serving as the main repository of knowledge, teachers must serve as 'actuators' who provide suitable correction to student progress.[35] While this manner of teaching keeps students more actively engaged, instruction becomes much less predictable, a feature of the learning model to which many teachers are averse.[36]

Further compounding the model are deficiencies of 'disclosure' and 'fidelity.'[37] In order to provide appropriate guidance, students must disclose their ideas visibly during the design process, an action that may not occur frequently enough for teachers to recognize, particularly in classrooms with high numbers of students.[38] Secondly, teachers are expected to accurately interpret students' disclosure of understandings and skills, upon which they must provide advice to support learning. Responses under these conditions are thus liable to be quite flawed, depending on the fidelity of a teacher's interpretations. Efforts must therefore be made so that projects represent professional work that permit teachers to make valid inferences about students' competencies.[20]

Methods of assessment in a project-based classroom are centered on authenticity, in which assessments require "students to use the same competencies, or combinations of knowledge, skills, and attitudes, that they need to apply in the criterion situation in real life."[39] In an ideal classroom, assessments are so well embedded in the curriculum that they are nearly indistinguishable from instruction itself, and there has been consensus – among educators, researchers, and policymakers – to utilize such alternative forms of assessment to better align valuable skills and habits-of-mind with instruction.[39] This strikes a significant chord in hands-on, design-based courses, where achievement of learning goals may not be measurable by traditional tests.[40] Evaluating abilities in communication, collaboration, and critical thinking is arduous, and in the case of group-based projects, must be done with the recognition that learning takes place under the influence of others, not in isolation.[41,42]

Research impetus

Each academy course centered on the development of a product (e.g., a solar water heater), suitable for solving a hypothetical real-world problem. In a typical course, the teacher spent a relatively short amount of time presenting related math and science concepts, and brief hands-on activities were conducted to reinforce the presented content before seguing into the main project. A key concern among the academy teachers (numbering four by the fall of 2013) was the ability for students to complete fully-functioning products with little to no demonstration of conceptual understanding or developed skills. The teachers therefore felt ill-prepared to assess achievement based on the students' completed products.

When the academy was created, the acquisition of disciplinary knowledge and skills was downplayed in lieu of more "universal" skills (e.g., communication) and engineering habits-of-mind, particularly collaboration, critical thinking, and affect towards the profession. However, calls to shift the direction of the program emerged, in part due to a substantial number of recent graduates who were not prepared to enter engineering college because they lacked core competencies, particularly in math. To address this issue, the teachers expressed a desire to identify methods by which students' knowledge and skills could be improved.

The course under study

The teachers were most interested in gaining an understanding of the academy from the students' perspectives, particularly those who had become accustomed to the learning model. To attain deep insight of students' experiences, a qualitative case study method was deemed an appropriate research approach. Two sections of a junior-level course totaling thirty-nine students – thirteen teams of three students each – were thus selected for evaluation in the spring of 2014.

The primary course project entailed the design and fabrication of full-scale hovercrafts. Final performance goals included an ability to hover above ground and propel forward while carrying a driver capable of steering the craft. Materials included a base cut from a 4'-by-8' sheet of wood, a tarpaulin to act as an inflatable "skirt," and a leaf blower and large fan to provide lift and propulsion. Creating an effective base and skirt assembly to minimize friction and maximize airflow in a single direction served as the primary design challenge.

The opening weeks of the semester were devised to compel students to reach an understanding of physical concepts related to the project. Topics related to flight in general, including the basics behind airfoils and Newton's third law of motion, were connected with brief activities intended to demonstrate basic principles. Students were responsible for researching topics specific to the field of flight and hovercrafts, for constructing small-scale and increasingly-complex hovercraft prototypes powered by balloons, computer fans, and hobby motors, and for conducting experiments on their prototypes, the data of which were collected and analyzed to support their final design ideas. Before the building process began, each team presented their initial plans as part of a "critical review" to receive feedback from the instructor and their classmates. To keep the teams on schedule after delving into construction, five progress checkpoints were utilized, requiring each team to balance their craft at a calculated center-of-mass, to properly construct mounts for the leaf blower and fan, and to demonstrate an ability to hover, propel forward, and steer. At the end of the semester, students were expected to summarize their design process and performance results in a manner representative of a professional presentation.

Course plans were written by an original academy teacher with a specific intention to generate interest in engineering and offer students an opportunity to gain construction experience. In this, the fifth iteration of the course, the course was instructed by a well-educated teacher with master's degrees in both education and physics. She had never taught the course before (in fact, she was the course's third different teacher) and was new to teaching in general, this being her second year in the profession and, notably, her first within the academy. Like all academy teachers, she split time with a core department, in her case, science. Though the conditions were far from ideal for observing a well-developed course, it was representative of common situations in which inexperienced teachers are tasked with managing an engineering-focused classrooms.

The curriculum was quite undetailed. The cooperating teacher was provided with four slideshow presentations, three worksheets, three activity plans, a handful of short videos, and the project agenda. Common among the academy courses, no learning goals were specified. The cooperating teacher, along with the author, added to the curriculum by creating daily warm-up problems and logs, worksheets, activities, and formative assessments. Due to the teacher's busy schedule, she had little time for making all of the changes she desired.

Researcher's role

As part of the National Science Foundation's Graduate STEM Fellows in K-12 Education Program, the author had been involved with the high school academy and its feeder schools for seven months prior to the beginning of the study. In this position, the author was responsible for developing and facilitating engineering-based lessons and activities as well as assisting students with product construction, experimentation, and problem solving as they progressed through the engineering design process. For the duration of the study, these responsibilities continued, necessitating that the distinct roles of classroom aide and researcher be carefully balanced.

The case study

Though the academy had become quite popular among the high school's students, major issues regarding academic achievement abounded, and program leaders hoped to address these inadequacies through curricular modifications. The proposed study intended to identify strengths and shortcomings of the project-based learning model in the manner it was being utilized within the academy. By characterizing the course as it was experienced by the students, and comparing these perceptions with those of the course instructor, her colleagues, and program administrators, salient points emerged. Study findings have supported curricular decisions within the academy, and aim to provide awareness to educators interested in high school engineering education and/or project-based learning. Though the study pertains to a single junior-level course in a unique environment, it is possible to draw connections to other settings. It is important to note, however, that making any such connections is the responsibility of the reader.

The study was guided by three research questions:

In a high school engineering classroom wherein project-based learning served as the educational model . . .

1) By which means did students achieve success?
2) What obstacles prevented expected achievement?
3) What tensions were generated?

For the purposes of this report, success is defined as math- and science-related content comprehension, disciplinary skills (including those related to computer-aided design, fabrication, and experimentation), and engineering habits-of-mind (particularly, critical thinking). Achievements were demonstrated through submitted assignments, verbal communication, and classroom behavior. Tensions are defined as opposing perspectives which strain curricular decision making, complicate classroom facilitation, or otherwise inhibit student learning.

Table 1: Data sources

Data	Source	Specifics	Purpose
Assignments	Students (39)	Products, worksheets, warm-ups & logs, essays, presentations	To evaluate learning goals & quality of student work
Formative assessments	Students (39)	Two quizzes, not included in grades	To evaluate comprehension of content
Grades	Students (39)	Twenty-five total assessments	To identify challenging areas for students, to evaluate course rigor
Likert surveys	Students (37)	Taken at end of course, 7 questions – scaled 1 to 5	To collect a class-wide quantitative sample on various topics
Open-response surveys	Students (37)	Taken at end of course, 12 questions – open-ended	To allow all students to provide individual perspectives & suggestions
Focus groups	Students (19)	Six groups of 2 to 5 students, semi-structured	To gain perspectives from a range of student types & probe for elaboration
Cooperating teacher disc's	Classroom teacher	Informal discussions, before and after classes	To gain an understanding of the teacher's perspective during the study
Teacher interviews	STEM teachers (4) & long-term sub	Semi-structured	To gain perspectives of those involved on a daily basis & probe for elaboration
Administrator interviews	HS & district administrators (4)	Semi-structured	To gain perspectives of those involved in big picture & probe for elaboration
Records	Students (26)	Socio-economic status, STEM & overall GPAs, ethnicity	To aid in creation of focus groups
Observations	Researcher	Recorded after each day's classes	To monitor instruction, behavior, & use of class time

Long-term engagement with a relatively small group of students was deemed an effective manner in which to capture their perspectives of the course, as well as of the academy as a whole. Views from educators heavily involved in the academy were also taken into account. To allow unanticipated findings to emerge, an inductive approach was utilized, providing flexibility and allowing for research design modifications in light of newly discovered evidence during the study. The theoretical perspective is best described by social constructionism, an aggregate of social constructivism and constructionism.

The undertaken research is best described as an ethnographic case study, by which situated descriptions of events and interactions could be generated. Evaluation of achievement necessitated collection of data from a wide range of sources as well as consideration of the contextual conditions and idiosyncrasies within the classroom that played a role in student learning. Details of the data sources are shown in Table 1. It is important to note that the student focus groups were created to provide a variety of perspectives. Somewhat homogenous groups were formed based on students' genders, backgrounds, classroom behavior, and academic achievement. Females, minorities, and low- and high-achievers were represented in proportions fairly representative of the entire class.

Data analysis and validity threats

A logical chain of evidence with support from multiple sources was imperative to add strength to the findings. One-on-one interviews and focus group discussions were audio recorded and transcribed. Text was initially categorized and quantified by utilizing a non-specific general accounting scheme, which allowed for portions of participant responses to be compiled into analytical units. A similar approach was taken for the open-response survey results. Students' completed work and formative assessment results were evaluated for content comprehension and skill mastery, while recorded observations of individuals' comments and actions supported these measures. Prominent topics from informal discussions with the cooperating teacher helped establish the teacher's intentions as well as her perception of the course.

Data analyses, assisted with the use of qualitative analysis software, were aimed at identifying repeatable regularities across all sources, necessitating examination for recurring events, common themes, and emergent connections, as related to the research questions. Topics most frequently raised were given corresponding weight to the findings, allowing for commonalities to be highlighted. This summarized data permitted a more straightforward approach in the classification of responses and identification of major themes. Of particular interest was evaluation of common student outlooks as compared to those of the teachers and administrators; conflicting perspectives were denoted as potential areas of miscommunication and misunderstanding among the academy actors. The purpose of the study was not only to identify the general consensus, but to also give a voice to individuals. Select accounts from discussions and interviews were included as a means to give better vision of the participants' experiences. To illustrate common viewpoints, quotes deemed representative of the specific perspectives were chosen. At the same time, salient points from those in disagreement with the majority were highlighted, helping to ensure that input from all was considered. It is important to note that the data analysis was carried out solely by the author.

Reactivity – the influence imparted by a researcher on a social situation and the influence imparted on a researcher by it[43] – was a prevalent validity threat in the study, as the effects of the author's role in the classroom were far-reaching. Discussions with the cooperating teacher about learning goals, for instance, led to lesson modifications. However, the author made a concentrated effort to serve at the behest of the teacher, supporting her as she spearheaded development of the course plans. In addition, the author consciously refrained from making any remarks that could have been construed as critical of the teacher's instruction so that she would not become defensive of her efforts. Reactivity effects were considered minimal when compared to the benefits of long-term involvement since the strong rapport established with the teacher and students generated open and honest discourse, allowing for the participants' true feelings to more naturally surface.

Researcher bias formed a second key validity threat, particularly since the author tended to view the academy as a traditional college preparatory program. This conflicted with the views of academy leaders who placed more emphasis on providing positive experiences in engineering, comparatively downplaying the importance of content mastery. While an effort was made to credit all possible measures of success, an overly critical view was likely held in regards to accomplished gains.

Discussion

A disconnect between content and hands-on work

"Right now, some of them, it's fun build time and that's what STEM classes are. And so they come in with that mentality and they don't feel they need to learn anything because it's just about building."

– Academy teacher

The cooperating teacher stated that the primary purpose of the course was to construct working hovercrafts. She did note that learning outcomes such as developing students' abilities to conduct research, to work with others, to use construction tools, and to give presentations in front of an audience were important as well, but both her words and actions prioritized product creation above all else. In fact, substantially more time was devoted to covering the daily task agenda and project instructions (6.6% of the class) than was allocated to lessons on content (3.9%).

This is not to say that content was neglected; the cooperating teacher made great strides to incorporate more content into the coursework. Yet doing so proved challenging, as identifying methods by which to explicitly connect knowledge and skills with the hands-on work posed a prominent barrier, an issue reiterated by most academy leaders. Part of this issue was caused by the teacher's unfamiliarity with the project and the lack of course details. That is, the teacher was unsure what expertise would ultimately aid with successful product creation. But much of this was also a consequence of the absence of learning goals. Without expected outcomes, identifying areas upon which to focus was not feasible, and due to a lack of available curricular development time, the teacher was in no position to revamp the course plans.

The academy curriculum had initially been designed under the assumption that projects would naturally "expose" students to math and science. In the case of the hovercraft course, the teacher expected that the topic of pressure, for example, would inherently find its way into the coursework, presenting a fitting opportunity to include the topic on a just-in-time basis to benefit the students' designs. Yet this opportunity failed to materialize. Instead, out of a need to formally present a lesson on pressure due to an impending formative assessment, a brief lecture and worksheet were given during the final weeks of the semester. Their inclusion within the project was anything but seamless, and several students voiced complaints, justifiably arguing that the additional work was entirely unnecessary for the completion of their crafts. Noted one, "She talked about physics, like the pressure stuff and the hovercraft, kind of separately. And I feel like she should have brought them together. Like we should've been doing the pressure to figure out how to build our hovercraft instead of just like pressure worksheets and then building our hovercraft."

The vast majority of delivered content was, at best, tangentially-related to the project. Lessons on airfoils, helicopters, and airships, for instance, which addressed the general topic of flight, did not provide information that could be directly applied to hovercraft design. In the students' eyes, content not explicitly tied to this purpose was generally considered superfluous. The lack of applicable science was, to many, the most discouraging aspect of the academy. As a result, when lessons were presented, students often tuned out. An academy teacher who also taught math expounded on this issue, saying, "I notice that when we give them lectures or try to teach them something, they get really bored really easily and really distracted. And they're level of focus in that [STEM] class for learning a math problem is way less than in my math class . . . I mean they should be able to go for a little bit, but I think for them, after like two minutes, they're like, 'What? This isn't math class.'"

Students were often distracted by the ever-present prospect of hands-on work, an issue that was exacerbated by the teacher's common practice of highlighting the significance of product creation. Simply put, building detracted from students' abilities to focus on content that was, in many ways, much more important. In recognition of this dilemma, a student explained, "You don't keep that [content] in mind. You're just like, 'Oh, we're just building something that hovers.' I think that idea just gets lost."

Despite their actions, the students generally believed the level of content in the academy should have been increased. For example, 14 of the 19 focus group participants expressed a desire for more content (sentiments that were put forth by eight of the nine academy leaders as well). And in response to statement "There should be more science and math in STEM courses," students replied with an average of 3.78 on a Likert-type scale (1 = strongly disagree, 5 = strongly agree). Unsurprisingly, all seven students in disagreement with this statement exhibited behavior and offered comments to the effect that they were completely uninterested in pursuing engineering or other STEM-related fields.

While there was agreement that increased rigor in terms of math and science would lead to better college preparedness, academy leaders were disinclined to include more content, a reluctancy attributable to the academy's overarching goals of engagement and inclusiveness. In other words, there was concern that emphasizing content would lead to less interest and retention, and it was believed that hands-on work was necessary to keep students engaged. This harkened back to the original intent of the academy in which positive experiences with engineering were highly prioritized, a topic discussed by an administrator who said, ". . . when we started, some of the curriculum was designed more around – there's no right way or politically correct way to say this – but it was more of get them to have fun and experience the fun side of engineering."

Yet this "fun" came at a cost. The administrator continued, "And we weren't selling what all of engineering actually requires." Of critical concern was the prevalence of students who were forming misconceptions of engineering, equating it with one where the fabrication of physical devices was the predominant activity of the profession and discounting the significance of math and science. That is, many students held the view that engineering amounted to "building stuff."

It is significant to point out that few students – 3 of the 19 focus group participants – enrolled in the academy out of a desire for hands-on work. An interest in math and/or science (9 students), a desire to improve their college applications (7), an aspiration to become an engineer (5), and an interest in learning about possible career pathways (4) were all more frequently mentioned. Still, there was a general hesitancy to include disciplinary content. The cooperating teacher, for instance, second-guessed her decision to incorporate additional math- and science-based coursework at times, concerned that it was limiting opportunities for construction, thereby taking the enjoyment out of class. Yet without content, it would have ceased being an engineering course. This balance between engagement and authenticity was touched on by an administrator who noted, "We don't want to turn too many people off of the idea of engineering, but at the same time we don't want to sell them on a false sense of what it is to be an engineer."

Problem-solving strategies

"There was nothing calculated or any measurements put into it . . . For about three class periods, that's all we did, just add more holes and see what it did."

– Academy student

In an ideal situation, as described by the cooperating teacher, "The kids should have to . . . have a strong understanding of whatever concepts in order to be successful with their project or build it." Yet the students commonly perceived math and science as non-essential tools. Of the 19 focus group participants, 17 claimed that they had found little to no use of math in the academy, while 14 denoted the same about science. A common viewpoint was expressed by a student who said, "As far as I've seen in STEM, you don't actually have to be that good at math. Maybe one person in your group has to be, but even then it's not crucial." Results from an open-response survey question, categorized in Table 2, demonstrate much the same.

Table 2: Categorized open-response survey results
"List the knowledge and skills have you learned in STEM courses."

Response type	Number of students (max = 37)
Construction skills	16
Teamwork	14
Critical thinking & creativity	13
Use of the design process	9
Science content	5
Math skills	4
Communication	3
Computer-aided design	3

Three of the five academy teachers expressed similar thoughts, explicitly noting that comprehension of content was largely unnecessary for project completion. The cooperating teacher recognized this issue, explaining that rather than applying their knowledge, students relied on other problem-solving strategies. As one example, she pointed out, ". . . the truth is, is that a lot these projects you don't need to understand everything to do, you just don't. You can watch a YouTube video of how to assemble this and build a lot of those things." She acknowledged the importance of improving connections between content and projects, continuing, "So how do we con them [laughs] into the learning part, is I guess like teaching the concepts so they're applicable."

But reliance on the internet for design ideas, while permitted, was not often done in the classroom. A more commonly employed problem-solving strategy was one grounded in intuition, illustrated by the following student quote: "I feel like you kind of just do what you see or what you would feel what works for your projects. Like if you think that would work, you kind of just have that instinct that something's going to work, you don't actually know the research behind it."

This sentiment was reiterated by another teacher, who explained, "So much of the projects that we do, I want to say, are kind of more tinkering-oriented, where if you just kind of have a general sense of how things kind of work, you probably can come up with a solution without doing any type of really in-depth analysis ahead of time and say, you know, is this going to work? I mean they just kind of sort of have a feel for it."

In line with the engineering design process, students were encouraged to frequently iterate their designs to optimize their devices. When their intuitions failed, students often turned to this strategy of trial-and-error. This approach was highly regarded by the students and generally perceived as *the* way to engineer. For example, in response to the statement "The best way to learn in STEM is by trial-and-error," students replied with an average score of 4.01 (1 = strongly disagree, 5 = strongly agree), with just five of thirty-seven disagreeing.

Even many of the students who came into the academy with expectations of applying newly-developed knowledge in their coursework had come to view trial-and-error as a more effective problem-solving strategy, demonstrated by the following student's comment: "I was expecting it to be a bit more math-based and not so much of the hands-on learning. But I've come to appreciate the hands-on learning more than just sitting down and doing the equations and thinking about it so much, rather than doing some trial-and-error. So it wasn't what I expected but I ended up liking it more than what I thought I was getting into."

Yet in reality, much of the students' actions could be better described by a label of 'guess-and-check.' That is, they failed to think critically about encountered situations, and instead resorted to making incremental modifications time and again, hoping for improvement. This strategy had served the students well in much of their previous academy coursework, but the hovercraft project did not offer a straightforward path to success and, in many respects, demanded a higher level of logical reasoning and creativity. Consequently, just 4 of the 13 groups were able to create working crafts, largely because the students lacked mindfulness during times of decision-making. This shortcoming was illustrated by comments from an exasperated student as her team struggled to identify a practical design; when asked about her team's alternative design ideas, she replied, "We're making bigger holes because we don't know what else to do." Rather than reflect upon their own tactics, a number of teams, convinced that the trial-and-error approach was effective despite a lack of progress, insisted that the provision of additional time would have undoubtedly led to success.

Aside from their own problem-solving strategies, students generally believed that the classroom teacher, and the academy teachers in general, should have provided more guidance. While it was largely understood that the teacher would not provide explicit solutions, a common complaint regarded the vagueness with which the she provided answers to design-based questions. One student, for example, vented, "When we'd be like, 'What do you think that we could possibly do?' she'd just be like, 'Oh, well, just think about it and try to fix it.' And that's just not really the answer I'm looking for."

With this perception of inadequate guidance, several students blamed their crafts' performance on the teacher. In her defense, some of the students' questions – like the one above – were far too broad. To attain more valuable feedback, students were implicitly expected to first demonstrate that they had seriously considered ways to address their design weaknesses before seeking help. While some individuals posed specific questions and presented ideas hoping to discuss possible outcomes and gain constructive criticism, others simply went looking for handouts, an approach misaligned with the learning model. This is not to paint the picture that students were overly reliant on the teacher. Some individuals, unfortunately often those requiring the most guidance, seemingly refused to ask for assistance when it was clearly needed. This placed responsibility on the teacher to offer help at frequent intervals.

Overall, the students greatly valued the freedom they received during class time. As a result, they were somewhat reluctant to declare that more teacher intervention was necessary. For instance, the statement "STEM teachers provide enough guidance during projects" yielded responses averaging 3.38 (1 = strongly disagree, 5 = strongly agree). Yet the results of the focus group interviews, when students were pushed to explain more about their thoughts on the role of the teacher in the classroom, painted a different story, shown in Table 3.

Table 3: Categorized focus groups statements about guidance

Topic	Number of students (max = 19)
More guidance is desired	14
Enjoy classroom freedom	12
Teachers don't need to provide solutions	11
Feedback is unclear	9
Important to ask specific questions	4
Guidance should get students on right track	2
Too much guidance provided	2
Quality feedback was provided	2

From the cooperating teacher's perspective, providing adequate guidance was a delicate balance between ushering students down an appropriate path versus challenging them to think critically. Due to the students' wide-ranging abilities and motivations, this balance varied team to team, and identifying the point at which to intervene was not well-defined. She self-admittedly took a "laissez–faire approach," providing the students with autonomy to take control over their own work. This constructivist-aligned strategy generated an environment in which several individuals thrived, but one which also created many frustrations for others.

Acquisition of engineering learning goals

"Without the STEM class[es], I wouldn't be introduced to just brainstorming and how we would work through a problem. It's one thing I really liked about the STEM academy, is kind of having the freedom to do and try what we wanted. That's one of the skills I'll take out of this class."

– Academy student

As intended by the academy founders, those involved in the program identified so-called 'soft' skills in areas such as teamwork, problem solving, and creativity to be the true strengths of the learning model, illustrated in Table 4. Yet due to the inherent difficulties of directly measuring such capabilities, the teachers did not attempt to assess students in these areas. Consequently, there existed no concrete proof of the purported gains.

Table 4: Categorized interview & focus group results – Perceived strengths of the academy

Topic	# Admin	Topic	# Teachers	Topic	# Students
Design process	4 (max = 4)	Teamwork	5 (max = 5)	Problem solving	11 (max = 19)
Teamwork	4	Problem solving	3	Design process	10
Creativity	3	Creativity	3	Critical thinking	8
Problem solving	3	Critical thinking	2	Teamwork	7
Responsibility	3			Building	6
Critical thinking	2			Creativity	3
Communication	2				

It is noteworthy that similar to the results of the open-response survey shown in Table 2, knowledge acquisition and skill development specific to engineering (e.g., computer-aided design and data collection) went largely unmentioned, indeed even more so in the focus groups. The low status of these learning goals was represented within the program's assessment structure as well, meaning that explicit demonstration of content and skill mastery was seldom required. In the hovercraft course, for example, most emphasis was placed on presentations (32% of the total grade), task completion (22%; e.g., daily logs), product performance (19%), and general craftsmanship (9%). By comparison, just three assignments necessitated correct application of math and science, representing 6% of the students' grades. Notably, average scores on these assignments were lower than any other assessment type.

Under this grading structure, the teachers felt ill-prepared to measure individuals' understandings, a point four brought up during their interviews. The hovercraft teacher spoke on this issue, stating, "At the moment they're not really being graded on what they learned per se. I think they're being graded mostly on their project and how it works and how they presented it at the end and how they're able to talk about it. . . . I feel like you could look at their grades and the best grades would be the ones who learned the most. I would feel confident to say that. But . . . 'learned' kind of implies that now they can do these things, and I don't know that the grading really reflects that."

As expected, students who performed better on the daily warm-up problems, worksheets, and formative assessments, and who offered more insightful reasoning during class-wide and one-on-

one discussions, also tended to produce better-performing hovercrafts. But this generality did not always hold true. The hovercraft teacher was well aware of this, explaining, “I think that can be very hit or miss. That if you’re going on performance alone, it doesn’t give you the full picture.” For this reason, presentations were given more weight under the belief that if students genuinely learned something, they should be able to explain it. Yet it was not demanded that design decisions be supported with evidence or performance outcomes be tied to relevant concepts. Rather, presentations were generally synopses of students’ design and construction processes and followed by basic performance data.

This disregard for connecting their projects to math and science content can be attributed to the reality that, to a large degree, students simply did not add much information to their factual knowledge bases. This issue that was evidenced by the manners in which they attempted to solve problems and presented their findings, which often lacked any discussion of underlying concepts. As one student pointed out, rather than “soaking in stuff and you’re tested on it,” as was common in her other courses, in the academy, “You don’t learn much information. . . . You just know you’re building something.” Perhaps most revealing of all were comments made during the focus group interviews – although four students mentioned that they attained an understanding of the basic concepts behind hovercrafts, *five* explicitly acknowledged the opposite, such as the student who expressed, “I feel like I learned not so much how hovercrafts work because even if you ask me now, I wouldn’t know how to answer.”

Findings

Research question #1: By which means did students achieve success?

The students undoubtedly made gains in critical thinking capabilities and other non-technical areas, as detailed by Table 4 and substantiated through discussions with individuals and teams about their experiences in the project-based model. But, due to the innate difficulty of explicitly assessing these attributes, students’ abilities in these areas were not directly measured; they were instead evaluated implicitly as a function of the quality of their finished products and presentations. These indirect measures were intended to serve as authentic assessments, offering students an opportunity to engage in work reflective of professional engineering while simultaneously providing teachers a means by which to evaluate students.

The heavy reliance on authentic measures, as well as a propensity to simply credit students for task completion, also minimized proof of gains in knowledge acquisition. The three assignments which required students to demonstrate explicit understanding – math-based worksheets – pointed to a rather poor grasp of concepts, even though this work was often completed with the help of teammates or the teacher. Likewise, results from two formative assessments illustrated a weak understanding of math content, though students were generally able to note basic science concepts presented during class time. Responses during focus groups and in the open-ended survey revealed that students believed they had gained understandings in a few content areas, such as forces of flight, pressure, and center-of-mass, but these concepts factored little into the hands-on work and could have easily been addressed without use of the project-based model.

A key limitation of assessing for attained knowledge was the fact that by the open nature of the learning model, each group encountered various topics. Groups learned about drawing arcs with specified radii of curvature, the effects of funneling propulsive airflow, and the drawbacks of wall skirts, but the concepts each group engaged with were distinct. In order to directly evaluate students on their understandings of each of these topics, the teacher would have needed to conduct unique assessments for each team (an incredibly time-consuming prospect), or controlled the project in such a way that each group encountered the "right" knowledge (thereby limiting autonomy).

Research question #2: What obstacles prevented expected achievement?

First and foremost, the lack of specific course learning goals limited the cooperating teacher's ability to foster student's knowledge and skill development. While the academy's Academic Standards and Grade Level Expectations established broad aims, they were too general to put into practice (indeed, they were ignored – the cooperating teacher was actually unaware of their existence). The teacher thus consistently struggled to identify areas in which the students could be expected to gain relevant knowledge and experience.

Moreover, identifying methods by which to incorporate disciplinary content into the project was inherently difficult. Rather than applying mathematical calculations and physical concepts during craft design, content was presented and discussed with little explicit connection to the project. Although content comprehension did aid in product development, it was completely possible to create a functional craft without any application of knowledge. Hovercrafts were therefore not so much engineered as they were created through an iterative process of trial-and-error.

Perhaps most prominent during the course, was the students' preoccupation with craft construction. This phase of the project was undoubtedly the most revered aspect of the course. Though it did foster engagement, the ubiquitous prospect of hands-on work detracted from students' ability to focus on knowledge and skill development, overshadowing much of their original motivations for enrolling in the academy.

Research question #3: What tensions were generated?

From the teachers' standpoint, an intention to serve students of all ability levels as well as a desire to engage students in engineering with "fun" activities consistently conflicted with the aims to prepare students for college. While hands-on work does not unavoidably necessitate that content be minimized, the reality was that math and science were indeed de-emphasized. Device construction and performance were viewed as the predominant purpose of the course, a viewpoint explicitly verbalized and implicitly underlined by an environment that valued task completion above knowledge attainment and procedural mastery. Although there was consensus for more math and science to be included within the curriculum, there was reluctance to do so out of concern that the program would become too exclusive, neglecting many of the very students the academy was established to serve. Yet jumping into the design process, purported to lead to more efficient learning, frequently hampered students who lacked basic competencies, resulting in non-ideal problem-solving strategies and frustration.

A delicate balance existed between fostering ingenuity through appropriate guidance and guarding against potential for frustrations due to futile endeavors. The learning model required autonomy to promote discovery of knowledge, but the students were unable to overcome many of the encountered challenges without assistance, nor were they likely to connect their projects with presented topics, thereby limiting the possibility of knowledge construction. By providing guidance, the teacher was able to address both of these issues. However, as more guidance was offered, the onus of learning shifted from student to teacher, and opportunities for individuals to develop their own understandings began to evaporate.

Proposed remediations

More time must be devoted to curriculum development. Since teachers split time between their core departments and the academy, little opportunity was available to modify and improve the lesson plans. When the academy was originally founded, the learning outcomes were left ambiguous with the intention that teachers would have the freedom to create courses that suited their interests and skill-sets. Yet with three or four preparation periods, the teachers lacked the time needed to make substantial changes to the plans that already exist, much less create their own from scratch.

Likewise, there was too much turnover for teachers to master the content. A key reason the cooperating teacher was unable to effectively incorporate math and science was because the topic was quite specialized. Simply identifying the knowledge that would indeed lead to better craft design was challenging. With more experience in the course, the teacher could have implemented more effective changes. But, like the teacher before her, she was unable to do so – another teacher (the fourth in four years) was assigned the course in 2015.

Because it proved unfeasible to assess individuals' understandings of content by means of their products and presentations, assessing for knowledge comprehension by traditional methods should be considered. Leveraging such assessments will tap into students' extrinsic motivations, compelling them to be more attentive when lessons are presented. More attention should be placed on disciplinary practices as well – for example, taking measurements, conducting experiments, organizing and analyzing data, and creating drawings – skills necessary to appropriately represent true engineering work. To ensure students prioritize these skills, their competencies must be rigorously assessed for accuracy (though doing so will require more time), and less attention by both the teachers' actions and the grading structure should be paid to the functionality of products. These modifications will should help mitigate students' reliance upon a problem-solving strategy of mindless trial-and-error. Critical thinking can be encouraged by requiring students to justify their design decisions and defend their findings.

While a primary goal of the academy is to develop students' abilities to conduct 'full' inquiries, they severely lack the necessary capabilities to do so. Efforts should be made to model proper inquiry methods, directly addressing the fact that students are expected to think critically through a problem rather than resorting to trial-and-error, and before seeking guidance. To a degree, the necessary capabilities should be introduced in their math and science courses, then reinforced in the academy. But academy instructors are being forced to teach many of these areas themselves – for example, basic computation and measurement skills – limiting opportunities for application.

Surprisingly, although the instructors also teach math and science courses, there is virtually no communication between the academy and these departments. To help mitigate the need for basic knowledge and skill building within the academy, efforts should be made to better align the coursework of the three departments, an admittedly difficult task.

An academy-wide policy on properly providing and requesting guidance should be established. The cooperating teacher was often unsure about when to intervene and when to suppress assistance. Since she commonly took the latter approach, students pursued poor design plans based on misconceptions, which quickly consumed their allotted build time and generated frustrations. On the students' end, they must be aware that asking for specific constructive criticism is necessary in order to receive pointed feedback. Many felt that the guidance was overly vague, but this had much to do with the manner in which they posed questions.

Most importantly, more specific learning goals for the academy must be established, allowing for more detailed course goals to support a learning progression throughout a student's tenure. By clarifying the expected outcomes of each course, teachers will be better prepared to design and facilitate coursework focused on distinct concepts.

References

1. Newmann, F. M., Secada, W. G., & Wehlage, G. G. (1995). *A Guide to Authentic Instruction and Assessment: Vision, Standards, and Scoring*. Madison, WI: WCER.

2. Morgan, J. R., Moon, A. M., & Barroso, L. R. (2013). Engineering Better Projects. In R. M. Capraro, M. M. Capraro, & J. R. Morgan, J. R. (Eds.), *STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, 2nd ed. (pp. 29-39). Rotterdam, The Netherlands: Sense Publishers.

3. Willingham, D. T. (2008). Critical thinking: Why is it so hard to teach? *Arts Education Policy Review*, *109*(4), 21-32.

4. Stout, M. (2000). *The Feel-Good Curriculum: The Dumbing Down of America's Kids in the Name of Self-Esteem.* Cambridge, MA: Perseus Publishing.

5. Furtak, E. M. (2009). *Formative Assessment for Secondary Science Teachers. Thousand Oaks, CA: Corwin.*

6. Smith, K. A., Douglas, T. C., & Cox, M. F. (2009). Supportive Teaching and Learning Strategies in STEM Education. In R. G. Baldwin (Ed.), *Improving the Climate for Undergraduate Teaching and Learning in STEM Fields: New Directions for Teaching and Learning*, 117, 19-32.

7. Holdren, J.P., Lander, E., Varmus, H. (2010). Report to the President. Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future. Executive Office of the President. President's Council of Advisors on Science and Technology.

8. Mehta, S. I. (1995). A method for instant assessment and active learning. *Journal of Engineering Education*, *84*(3), 295-298.

9. Felder, R.M., Woods, D.R., Stice, J.E., Rugarcia, A. (2000). The Future of Engineering Education II. Teaching Methods That Work. *Chemical Engineering Education*, 34(1), 26-39.

10. Mills, J. E., & Treagust, D. F. (2003). Engineering education – Is problem-based or project-based learning the answer? *Australasian Journal of Engineering Education*, *3*, 2-16.

11. Bender, W. N. (2012). *Project-Based Learning: Differentiating Instruction for the 21st Century*. Thousand Oaks, CA: Corwin.

12. Ravitz, J. (2009). Introduction: Summarizing Findings and Looking Ahead to a New Generation of PBL Research. Interdisciplinary Journal of Problem-based Learning, 3(1).

13. Thomas, J. W. (2000). *A Review of Research on Project-based Learning*, San Rafael, CA: Autodesk Foundation.

14. Perrenet, J. C., Bouhuijs, P. A. J., & Smits, J. G. M. M. (2000). The suitability of problem-based learning for engineering education: theory and practice. *Teaching in higher education*, *5*(3), 345-358.

15. Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: a model and seven principles of good feedback practice. *Studies in higher education*, 31(2), 199-218.

16. Bransford, J. D., Brown, A., & Cocking, R. (2000). How people learn: Mind, brain, experience and school, expanded edition. *DC: National Academy Press, Washington*.

17. Slough, S. W. & Milam, J. O. (2013). Theoretical Framework for the Design of STEM Project-Based Learning. In R. M. Capraro, M. M. Capraro, & J. R. Morgan, J. R. (Eds.), *STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, 2nd ed. (pp. 15-27). Rotterdam, The Netherlands: Sense Publishers.

18. Bangert-Drowns, R. L., Kulik, C. L. C., Kulik, J. A., & Morgan, M. (1991). The instructional effect of feedback in test-like events. *Review of educational research*, *61*(2), 213-238

19. Farenga, S. J., Joyce, B. A., & Ness, D. (2006). Adaptive inquiry as the silver bullet: reconciling local curriculum, instruction, and assessment procedures with state-mandated testing in science. In M. McMahon, P. Simmons, R. Sommers, D. DeBaets, & F. Crawley (Eds.), *Assessment in Science: Practical Experiences and Educational Research* (pp. 41-51). Arlington, VA: NSTA Press.

20. Gulikers, J. T., Bastiaens, T. J., & Kirschner, P. A. (2004). A five-dimensional framework for authentic assessment. *Educational Technology Research and Development*, *52*(3), 67-86.

21. Perrenet, J. C., Bouhuijs, P. A. J., & Smits, J. G. M. M. (2000). The suitability of problem-based learning for engineering education: theory and practice. *Teaching in higher education*, *5*(3), 345-358.

22. Schmidt, W. H., Burroughs, N. A., & Cogan, L. S. (2013). On the Road to Reform: K-12 Science Education in the United States. In R. M. Latanision (Ed.), *The Bridge: Linking Engineering and Society*, 43(1), (pp. 7-14). National Academy of Engineering.

23. Berger, R., Rugen, L, & Woodfin, L. (2014). Leaders of Their Own Learning: Transforming Schools Through Student-Engaged Assessment. San Francisco, CA: Jossey-Bass.

24. Wiggins, G., & McTighe, J. (2011). *The Understanding by Design Guide to Creating High-Quality Units* (pg. 53). Alexandria, VA: ASCD.

25. Kelley, T., Brenner, D. C., & Pieper, J. T. (2010). PLTW and Epics-High: Curriculum Comparisons to Support Problem Solving in the Context of Engineering Design. Research in Engineering and Technology Education. *National Center for Engineering and Technology Education*.

26. Roselli, R. J., & Brophy, S. P. (2006). Experiences with formative assessment in engineering classrooms. *Journal of Engineering Education, 95*(4), 325-333.

27. Schunn, C. D. (Fall 2009). How Kids Learn Engineering: The Cognitive Science Perspective. *The Bridge*, 39(3), 32-37.

28. Felder, R. M., & Brent, R. (2004). The ABCs of Engineering Education: ABET, Bloom's Taxonomy, Cooperative Learning, and So On. Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition. Session 1375.

29. Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering education*, *78*(7), 674-681.

30. Strobel, J., & van Barneveld, A. (2009). When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms. Interdisciplinary Journal of Problem-based Learning, 3(1).

31. National Research Council (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.

32. Morgan, J. R., & Slough, S. W. (2013). Classroom Management Considerations. In R. M. Capraro, M. M. Capraro, & J. R. Morgan, J. R. (Eds.), *STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, 2nd ed. (pp. 99-107). Rotterdam, The Netherlands: Sense Publishers.

33. Kirschner, Paul A., Sweller, John, & Clark, Richard E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75-86.

34. Johnston, A. (2008). Demythologizing or dehumanizing? A response to Settlage and the ideals of open inquiry. *Journal of Science Teacher Education*, *19*(1), 11-13.

35. Bjorklund, S. A., Parente, J. M., & Sathianathan, D. (2004). Effects of Faculty Interaction and Feedback on Gains in Student Skills*. *Journal of Engineering Education*, *93*(2), 153-160.

36. Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability (formerly: Journal of Personnel Evaluation in Education), 21*(1), 5-31.

37. Cowie, B., & Bell, B. (1999). A model of formative assessment in science education. *Assessment in Education: Principles, Policy & Practice*, 6(1), 101-116.

38. Wang, L., Maccann, C., Zhuang, X., Liu, O. L., & Roberts, R. D. (2009). Assessing Teamwork and Collaboration in High School Students: A Multimethod Approach. *Canadian Journal of School Psychology, 24*(2), 108-124.

39. Darling-Hammond, L., Ancess, J., & Falk, B. (1995). *Authentic Assessment in Action: Studies of Schools and Students at Work*. New York, NY: Teachers College Press.

40. Tran, N., & Nathan, M.J. (2010). An investigation of the relationship between pre-college engineering studies and student achievement in science and mathematics. *Journal of Engineering Education*, 99(2), 1-15.

41. Zhang & Matthew W. Ohland (2009) How to Assign Individualized Scores on a Group Project: An Empirical Evaluation, Applied Measurement in Education, 22:3, 290-308.

42. Kruck, S. E., & Reif, H. L. (2001). Assessing Individual Student Performance in Collaborative Projects: A Case Study. *Information Technology, Learning, and Performance Journal*, 19(2), 37.

43. Maxwell, J. A. (2013). *Qualitative Research Design: An Interactive Approach* (3rd ed.), Los Angeles, CA: SAGE Publications.