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

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The STEM academy

After nearly two years of research and preparation to rejuvenate a downward-sliding high school, a STEM academy opened in a newly-constructed wing of the school in the fall of 2009. The intent of the program was not simply to cater to the highest achievers, but to serve the needs of the community, one in which a large minority population resided. Though the program carried the 'STEM' label, engineering was always intended to be the primary focus. Courses were designed to introduce students to engineering, and it was hoped that many would consider the field for college and career. Hands-on group projects formed the bulk of the curricula, providing a semi-authentic feel of engineering work and an atmosphere that was envisioned to highly engage the students.

Incoming freshmen were enticed by a one-on-one laptop initiative, the prospect of no tests and very little homework, and a formal agreement with an in-state engineering college which offered guaranteed acceptance to those who met specified requirements. To encourage students of all abilities to apply, admission standards were kept relatively low, the key condition being an ability to perform at grade level in math. For those below this level, provisional acceptance could be offered. Four years after the academy opened its doors, 340 students were enrolled (about one-quarter of the school's population), with demographics of 35% minority, 35% female, and 23% low socio-economic status. While these rates fell short of matching the school itself, compared to those earning engineering degrees across the nation (13% minority, 18% female[1]), the academy was an overwhelming success in diversity.

The learning model

Originally unable to afford canned curricula, two of the school's science teachers – one of whom had a degree in engineering, the other with a background in the construction industry – were tasked with creating the lesson plans. Though neither had experience with engineering education, faculty members from the partnering college provided guidance. Rather than simply focusing on the development of understandings and procedural skills, it was deemed that fostering students' collaboration and communication abilities as well as their critical thinking were higher priorities. In addition, it was hoped that students would come away from academy courses with positive engineering experiences. Courses were therefore rooted in project-based learning, seen a way to provide an accessible and engaging environment to individuals of nearly all ability levels.

Literature review

In project-based learning, classwork is student-driven, at least to a degree, whereby teachers are expected to behave more as facilitators, helping to guide students in investigative activities and product development.[2,3] Students, for their part, should be urged to assume ownership for their learning.[4] The learning model has been cited as an effective method for differentiation, allowing students to learn and work at their own paces.[5] Yet a degree of self-regulation – the manner in which students are able to monitor and control their own thinking, motivation, and behavior during the learning process[6,7] – is necessary to optimize the learning benefits of any learner-centered classroom. Expert learners, those with high self-regulatory capabilities, are well-suited to project-based learning; those who lack self-monitoring skills often experience difficulties in student-directed situations that require them to initiate inquiry, direct investigations, manage time, and use technology productively.[2]

Instructors of project-based curricula, particularly those new to the learning model, often struggle to balance the active engagement of students and the relative chaos that can easily emerge.[8] Because students must manage their own time and materials, collaborate with teammates as they see fit, and make their own decisions, project-based learning is typically less-structured than other active learning methods.[9] As a result, classrooms may appear unorganized, off-task, and out of control. In high school classrooms, where students with vastly different maturity levels, language abilities, and intellectual capabilities must work together, project-based lessons can test a single instructor's ability to involve all (or most) students in productive activities without sacrificing content or losing control of the class.[10]

If students perceive that a classroom environment impedes their efforts to learn, their aspirations can suffer.[11] Taking measured steps to provide a supportive environment is critically important in STEM fields since students commonly fail to remain engaged in course material. The reason for this discontent is typically not due to overly challenging subject matter or disinterest in content, but is more often caused by poor-quality learning environments.[12]

An ability to work within groups is considered one of the major workforce skills of the 21st century, and one with particular importance in engineering.[13,14,15,16] Social settings within classrooms are thus seen to play critical roles in the educational process. In the same vein, learning is less often being viewed as a private activity.[17] Students who work within well-functioning teams tend to learn more and at a deeper level as compared to those in lecture-based courses, and collaborative work can improve students' motivation, self-confidence, and dispositions towards the subject matter.[18]

Collaborative settings provide opportunities for co-construction of knowledge.[19] However, it is common for students to divide tasks, an effective means for completing work, but one which undercuts the intent of collaboration. In order to foster teamwork skills such as communication, leadership, conflict resolution, and project management, a project cannot be divided and worked on individually; there must be positive interdependence.[20] That is, students must rely on each other to attain success. This includes goal interdependence (a shared vision of the project), role interdependence (fulfilling assigned roles), and reward interdependence (a shared grade).

Yet in an ideal cooperative learning environment, there must also be individual accountability. Without each team member taking responsibility for his or her own role within a group, student achievement can suffer.[18] Group assignments are inherently problematic because they attempt to merge diverse skills and personalities in hopes that teammates will work towards common goals.[21] Students who are not truly invested in a course or who lack maturity commonly take advantage of group-based work and 'hitchhike' on the efforts of their teammates.[22] At the other end of the spectrum, students who do not trust the capabilities of their teammates and feel a need to control situations often dominate their groups, taking on more of a role than is appropriate and disallowing other members an opportunity to fully participate.[23]

Students typically view overall group grades as unfair, and these grades must be adjusted for individual performance.[22] If grades do not reflect individual efforts, students cannot be held accountable, hard-working students may resent others, and teachers may appear to permit laziness and irresponsibility. Yet it is challenging to evaluate the level of knowledge or skills students have attained during a group project, placing a burden on teachers.[24] Of the commonly utilized assessment strategies in group-based settings, all possess drawbacks. These include self-assessments (over-inflated grades), peer assessments (heavily influenced by social relationships with classmates), situational judgment tests (questions about various scenarios; objectivity is difficult), behaviorally-anchored teacher-rating scales (difficult to observe all students), and team interviews (prohibitively time intensive).[24,25,26]

To model professional work, project-based methods often utilize authentic assessments. This assessment strategy requires students to apply the same knowledge, skills, and attitudes as would professionals.[4] Due to their connections to the real-world, authentic measures are more likely to motivate students.[27] Higher-order thinking skills such as problem solving are fostered as well.

Purpose of the study

Academy leaders aspired to offer the curriculum as a model for high school engineering education. Although the teachers and administrators were pleased with the progress made during the program's initial four years, there was consensus that ample opportunity for improvement remained. Student behavior was a major issue which needed to be addressed – the teachers voiced concerns that a substantial number of low-achieving students persisted in the program, potentially weakening the learning environment.

The teachers were quite interested in gaining a better understanding of the academy from the viewpoint of their students in order to make positive changes. It was anticipated that doing so would cultivate a more comfortable classroom atmosphere, allowing the teachers to better support individuals' needs. At the same time, there were perceived flaws within the learning model and grading structure that limited the teachers' abilities to engage the students as expected. Assessing these issues was deemed necessary to help provide key insight from which to base future curricular decisions.

Though this study intends to paint a clear picture of a classroom in this particular school, the findings from this work are not meant to simply support the academy, but to provide an awareness of the beneficial features and potential pitfalls of project-based learning and/or engineering courses in similar environments. Educators using this case as guidance will have better justification for the creation, modification, and/or facilitation of such courses. Since there is currently little research upon which to base curricular decisions in high school engineering[26] – demonstrable by the large number of outside educators visiting the school in order to learn more about its unique academy – the findings provide much-needed support for this evolving educational field.

A junior-level course was chosen for this case study because it represented typicality within the academy. The course had been taught four prior times and followed the general curricular structure of the program, meaning that there was a focus on content and introductory activities during the first weeks of instruction, followed by an extended design and construction phase. In addition, the teachers expressed a desire to learn about the experiences of students who had been in the academy for several years.

The course centered around the creation of hovercrafts, comprised of wooden bases (typically about 6'-by-3' in surface area), an inflatable tarpaulin "skirt", and powered by a leaf blower and large fan. Students were expected to develop their final crafts after creating smaller prototypes, collecting relevant data, and devoting a substantial amount of time to optimizing their vehicles by means of the engineering design process. In the spring of 2014, thirty-nine students were enrolled in two sections of the course. The cooperating teacher, who represented the course's third different instructor, was new to the school, having just completed her first semester in the academy. She held master's degrees in physics and education, but had essentially no engineering experience. Course plans had been written by an original academy teacher with a primary goal of fostering interest in engineering through an attention-grabbing project that demanded a substantial amount of hands-on work.

Researcher's role

The primary author served as a classroom aide for the entirety of the semester-long course. His position was sponsored by the National Science Foundation as part of the Graduate STEM Fellows in K-12 Education Program, which places graduate students within classrooms to design and facilitate lessons and activities for schoolchildren. While conducting research, the author was also responsible for working with the cooperating teacher to develop the existing curriculum, deliver lessons, and assist students with experimentation, construction, and problem solving.

Theoretical perspective & research questions

To provide insight into the academy, it was considered necessary to capture the subtle dynamics and interactions within a single classroom as well as investigate the beliefs and understandings of the academy from the perspectives of key participants. Determining commonly shared and opposing viewpoints helped identify the advantages and limitations of the learning model utilized in the classroom. The theoretical perspective of the study is based on social constructionism, a blend of social constructivism and constructionism. This perspective, a subset of interpretivism, best embodies the learning theory of the course under investigation.

The study was guided by the following 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 was defined as student behavior representative of professional engineering. Such behavior included an ability to collaborate with teammates, to actively participate in discussions and activities, and to come away from the course with positive experiences in engineering. 'Tensions' were defined as opposing ideals of those within the academy which inhibited the academy teachers' abilities to promote student engagement.

Research methodology

The study is best described as an ethnographic case study. A qualitative study with an inductive approach and long-term involvement was utilized. The research was conducted without a driving priori hypothesis, allowing for unexpected phenomena to emerge. Contextual conditions and idiosyncrasies within the classroom were evaluated from various data sources, providing an opportunity to produce more accurate understandings of the events in the classroom and interactions among participants. To acquire useful insight of student accomplishments and the value of the program as perceived by those involved, a well-rounded approach to data collection was undertaken. The data sources are listed in Table 1.

Table 1: Data sources

Data	Source	Specifics	Purpose
Assignments	Students (39)	Products, worksheets, warm-ups & logs, essays, presentations	To evaluate student interest & collaboration in coursework
Grades	Students (39)	Twenty-five total assessments	To evaluate manners in which students were assessed
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 behavior, collaboration, engagement & use of class time

All four STEM teachers, as well as a long-term substitute who had recently retired from teaching physics and engineering, were interviewed. Among these teachers, four had degrees in engineering (the cooperating teacher being the exception), they had each taught for at least seven years (again, the cooperating teacher was the exception), and all but one also taught physics (the other was a math teacher). Despite the cooperating teacher's lack of engineering experience, the study was viewed as a practical means to evaluate a realistic situation of an engineering-based course being taught by a non-engineer.

The administrators included the school principal and three directors charged with overseeing STEM-related programs at the high school and district level. While none of the administrators had experience in engineering, two had served as science teachers in the past (one of whom had taught within the academy) and one was a former math teacher. Three of the four had been instrumental in the creation of the academy.

To promote honest input from students, somewhat homogeneous focus groups were formed based on gender, background, observed classroom behavior, and academic achievement. Among the nineteen students, there were seven females, five underrepresented minorities, and four of low socio-economic status, fairly representative of the class as a whole. All focus groups and the cooperating teacher interview were conducted at the conclusion of the course.

Data analysis and validity threats

The primary goal of the data analysis was to locate commonalities with regards to the research questions. Qualitative analysis software was used to assist with the categorization of the data. More weight was given in the findings to those areas most frequently raised by the participants, particularly those substantiated by multiple sources. Conflicting areas, both among students themselves and between students and academy leaders were noted for further investigation. In order to present better insight into the classroom setting, participant quotes were highlighted, selected based on their general representativeness of common perspectives. Yet a key strength of qualitative studies is the ability to give voice to minority viewpoints, and salient topics discussed by individuals, particularly those opposed to the majority, were taken into consideration. General trends specific to the course were noted, with those substantiated by multiple sources and various participants given more weight.

Recorded interviews were transcribed and quantified by utilizing a coding scheme, allowing for identification of main themes across various perspectives. Patterns were applied when possible, allowing the data to be summarized into a more manageable number of categories. Similar steps were taken with the open-response survey results. Frequent discussions with the cooperating teacher, direct classroom observations, Likert-type survey results, and students' completed assignments helped with evaluation of classroom engagement and collaboration. It is important to note that the entirety of the data was collected and analyzed solely by the author.

A concerted effort was made to serve at the behest of the cooperating teacher so as to gain a better view of how the course would have transpired had no researcher been present. At the same time, the author attempted not to influence the behavior of the students by refraining from remarks that could have been interpreted as critical so that the students would not change their behavior on account of his presence. Yet because the author played a very active role, both in the classroom and during lesson planning, the extent to which he influenced the study was far-reaching, posing a non-trivial validity threat. However, the opportunity to build strong rapport with the participants permitted a more comfortable environment in which most were quite willing to share their genuine beliefs about the course and academy. Thus, any drawbacks due to 'reactivity' (i.e., the researcher's influence in the classroom and the classroom's influence on the researcher[28]) were perceived as minimal when compared to the benefits reaped from this long-term involvement.

Another validity threat existed in the form of researcher bias. Because enjoyable engineering experiences were highly prioritized in the academy, the cooperating teacher more readily accepted a somewhat chaotic environment. The classroom may have been viewed too critically, occasionally seen as lacking in control because these conditions did not align with the typical setting of engineering college classrooms. In addition, the author was inclined to compare the behavior of the students with behavior typical in an engineering college. Consequently, expectations were likely too high at times. To mitigate effects from these views, efforts were made to find value in enjoyable activities by crediting instances when students appeared engaged in positive experiences, as displayed through their comments and actions.

Discussion

Negative effects of hands-on work

"So right now students come into the engineering classes – and this is really obvious at [the high school] – it's so laid back, they're all comfortable, they just want to relax."

– Academy teacher

Students loved to build. As shown in Table 2, hands-on features dominated students' interests in the course as well as their suggestions for improving it. This component of the curriculum was a major reason for students to engage in coursework, as is intended by the learning model. Unfortunately, some students remained in the academy solely for this reason, such as one who stated, "[Building is] probably why I stayed in STEM, otherwise if it was like just learning, I probably wouldn't stay."

Table 2: Categorized results from open-response survey – Best features & Suggestions

"What were the best parts of this course?"			"List any suggestions you have for improving this course."	
Topic	# Students		Topic	# Students
Building	19 (max = 37)		More build time	13 (max = 37)
Working with friends/teammates	9		More/better materials	11
Testing to see if it works	6		More research before building	6
Designing hovercraft	4		More guidance	5
Satisfaction of successful project	4		Nothing	4
Working on a full-scale device	3		No intro projects	4
Riding hovercraft	3		Less research	2
Nothing	3		Learn more math	2

At the same time, unaware that hands-on work played such a large role in the classroom, many students had very different expectations before entering the academy (as noted by 11 of 19 focus group participants). Several even spoke of former STEM classmates who left the academy because they were totally uninterested in the physical work. One student explained, "They just didn't think it was so much building, hands-on, and stuff like that. They thought it was just going to be more like, you take more science classes and math classes."

Yet building quickly came to dominate classroom actions, and once students became enamored with the idea of hands-on work, many had little patience for much else in the classroom. In the hovercraft course, the beginning weeks of the curriculum called for background research and introductory activities that required data collection and analyses. Yet many students were uninterested in these tasks. Sensing their discontent, the teacher premised a lecture one day with, "I agree that there's a lot of presentations and writing, but there's only so much I can do. . . . Bear with me for the next fifteen to twenty minutes. I'll make this as interesting as I can."

A few weeks later, the students' impatience reached a boiling point after the teacher assigned a follow-up experiment similar to one they had just completed, perceived by some as another non-essential task. A student burst out, "This was supposed to be the fun STEM class!" Another chimed in, "I agree! Usually STEM classes have two weeks of research, and then only building. This class has like eight weeks of research!"

The teacher later confided that she was worried the course was not "fun" enough. She felt too much time was devoted to lectures (which accounted for less than 4% of class time), and found a substantial number of students unwilling to actively participate in class discussions and activities. They simply wanted to start the construction process.

The students' levels of engagement varied considerably. Several regularly and voluntarily participated in the classroom, offering ideas, asking in-depth questions, spurring further investigations. These students showed a genuine interest in understanding the science behind their observations. But a considerable portion were oriented towards work avoidance, and sought to put forth as little effort as possible. When given the opportunity to design their own experiments, for example, a student persuaded his teammates to alter their independent variable solely because it would require less work. Similarly, some decided to modify the shape of their hovercraft bases to much simpler geometries so that the required math and construction would be minimized.

The cooperating teacher noted these issues and became increasingly frustrated with what she viewed as poor attitudes among a sizable chunk of the classroom. She noted that they did not come to class prepared to learn, were inattentive when instructions and lessons were presented, and she often felt that she had to "baby" them through assignments. Speaking on the topic of written work, she summarized that there were three types of students in the classroom:

1. Those who tried to solve posed problems and checked their work with classmates
2. Those who waited for others to do the work and then wrote down the answers
3. Those who did not care and did not do the work

In the words of one teacher, too many students were in the academy "for the wrong reasons" and remained only "because classes are fun" and "because they get to come and screw around and build stuff." While the emphasized hands-on projects of the learning model were undoubtedly capturing students' interest, they were also shifting focus away from the more-important engineering-relevant learning goals in the academy. An administrator addressed this issue, noting that because project-based learning had been trickling down to the lower grades of the school district, courses needed to shift their emphases to improve students' skill-sets. She stated, "Now it's really about, okay, what technical skills – math, science, technology – do you need to be able to truly access engineering at a higher level. . . . Because if we just keep having kids build stuff, well they're done, they got that. I mean after fifth grade, they've got that."

Consequences of the assessment structure

"I think the goal of the STEM academy is to make them excited about engineering. One of the reasons why I like the STEM academy is I do feel like any student who wants to come into the STEM academy and who is interested in it from middle school can. And it gives them a chance. And I just really like that they have that chance. Whereas if it was like an IB [International Baccalaureate] program or something, they just wouldn't have that chance. . . . I feel like it really sets this place apart even if it isn't as rigorous as it should be. I think it really helps to serve the population."

– Academy teacher

In lieu of homework and tests, students were assessed by the performance of their products and the presentation of their results. While a shift away from traditional methods need not unavoidably lessen the rigor, the hovercraft students generally viewed the academy as undemanding. In fact, when the focus group participants were asked to comment on the gains they had made since joining the academy, the most commonly raised topic was that coursework was quite easy. And, in response to the statement "STEM courses are too difficult," students replied with an average of 2.26 on a Likert-type scale (1 = strongly disagree, 5 = strongly agree). Just one student was in agreement.

From the teachers' point-of-view, traditional assessment methods, in a way, directly conflicted with the goals of the academy. The cooperating teacher spoke on this topic, saying, "I think with the spirit of the program, the idea is that rather than test, the test is their project and the test is presenting it . . . One of the overarching goals for STEM programs, or at least the way they sell them is like, kids up, kids building things, kids engaged. So tests don't suit that scenario as much." Added her colleague, "I feel like [the lack of homework and tests] goes along with the intent of the program right now, and the idea that we want to make them interested in engineering."

But owing to the assessment structure, students did not take notes during lectures and many put forth little effort when completing daily warm-up problems, logs, and other written assignments, knowing that they would not be rigorously evaluated on their quality of work. Indeed, much of this work was assessed solely based on completion, the "volume" of information written, as the cooperating teacher noted. This practice was employed more out of pragmatism than a lack of desire to assess students – grading the assignments would have generated a time-consuming mountain of paperwork when the teacher's time was already a scarce commodity. Besides, due to the group-centeredness of the classroom, much of the work was done with the help of others (or with the teacher's help) and did not truly represent individual achievement.

In order to keep groups on task during the construction phase of the project, progress checkpoints were put in place. Although several students worked diligently throughout the project, many did not possess the self-regulation necessary to take responsibility for efficiently completing tasks without extensive oversight. Then, as checkpoints loomed, there was often sense of urgency. An administrator raised this issue while speaking about the senior capstone course of the academy, commenting, "Students sometimes are the best procrastinators and they're kind of going, 'Oh, at the end I've got to rush through and I've got to get all these things done.'"

Some of those who reached checkpoints early, and thus had several days before the next assessment, were often disinclined to continue working. Consequently, it was not uncommon to see students socializing, on their phones, or playing games. While clearly not a worthwhile use of class time, these students were nonetheless on schedule. A group who fell into this category, having created a well-functioning craft with several class periods remaining, accomplished very little during the final stretch of the project. In comparing the situation to a college or workplace project, the cooperating teacher said, “I don’t think that I should punish a group for figuring it out early, and I can’t blame them for not working and not wanting to ruin it.”

The learning environment

“There’s definitely a split atmosphere, where there’s some people that need the grade, for one. Two, they actually enjoy the class. And three, they actually look forward to it and they’re like, ‘Alright we have STEM today, I’m excited.’ Then there are the people that have somewhere else better they have to be. And they really just don’t care. They’re there just filling space, breathing oxygen. They’re not trying at all. . . . I mean I hate to say it, but there’s some people that just don’t want to be there. And it’s not fair to the rest of us.”

– Academy student

The students enjoyed the overall learning environment, a point mentioned by 10 of the 19 focus group participants (no students stated they disliked it). Eight participants specifically noted their partiality towards the relatively high amount of autonomy afforded in the classroom; the freedom to approach the project as they saw fit was a well-received change from traditional lecture-style classes. But as noted by teachers and students alike, those with seemingly little motivation to work hard were an incessant source of frustration. Worried that the classroom environment was pushing some students away, one teacher commented, “While it’s okay for the program to help some people decide that that’s not what they want to be, I don’t want the program to be the reason why they don’t consider it.”

This was not a clear-cut issue. Many students had no qualms with their classmates, oblivious (or not forthcoming) about the fact that a small yet nontrivial portion of the class put forth little effort. Yet for others, particularly those who expressed genuine interest in pursuing a STEM-related career, the behavior of a select few hampered the seriousness of the classroom. Some went as far as to suggest raising the academy entrance requirements as a way to mitigate the number of disruptive students. This idea had already been discussed by the academy teachers, two of whom explicitly stated that doing so would likely help others focus. Nevertheless, the proposal was ultimately disregarded due to the emphasis placed on inclusiveness.

Notably, raising the academic bar for enrollment would have made little to no effect on the overall professionalism in the classroom. The frustrations recalled by the study participants were always due to behavioral, not cognitive, problems. No student or teacher, nor administrator for that matter, ever made any mention of a student’s intellectual abilities as a distraction or difficulty of any kind in the classroom. This issue was encapsulated well by a student who explained, “Contribution and participation is just a major thing. I see lots of people slacking off in STEM and I don't believe they should get the same grade as the people who actually try. And even if they don't succeed, at least they're trying and learning."

Group work

"I really enjoy working in a group because I kind of tend to fall into a one-track way of thinking . . . It also creates potential for a much stronger and better designs because you have three people looking at it from three different ways, rather than just one person looking at it their way only."

– Academy student

The study participants considered teamwork to be a significant strength of the academy, mentioned by all nine academy leaders and noted by 14 of 37 students as an attained skill (second only to construction skills). In the focus groups, many students noted the importance of working with others, a practice which resulted in stronger projects. Like hands-on work, group-based activities were incorporated into the curricula as a means to make classes more engaging, a goal that was undoubtedly achieved, as evidenced by students' classroom actions and comments. Said one student on the subject, "I'm able to hang out with my friends while we work and so it makes STEM more enjoyable. It makes me want to come to class." Wrote another, "Getting to do the project with my friends was a large bonus. I had fun every time I came into class."

Yet similar to hands-on work, group work also encouraged students to remain in the program even if they were completely uninterested in the subject matter. This issue was exemplified by a student who, when asked to list the best parts of the hovercraft course, wrote, "I don't really have good parts it was all in all frustrating. However, I enjoyed working with my team."

Academy projects were designed with the intent that students would be compelled to problem solve together and learn from one another. In addition to adding a degree of authenticity, teamwork was necessary from a practical standpoint simply because effectively addressing every student's needs in a project-based environment – where individuals often needed support with unique problems due to the open nature of the design process – was beyond the means of a single teacher. The students were thus encouraged to rely on one another for support.

But teammates did not always collaborate as expected. Rather than working together through assignments, many believed that task delegation was the most reasonable approach since it lessened the workload, illustrated by one student's comments: "I think a group dynamic makes the building and presenting process a lot less stressful because there's work that can be divided up." In the minds of some students, group assignments were a necessity because they felt unprepared to handle the work alone. Expressed one such student, "I like working in groups because then we actually get stuff done. If it was just me, I feel like I couldn't get any of this done by myself."

By delegating tasks to those with the greatest strengths in particular areas, the students were in fact behaving in an authentic manner. But they often avoided areas in which their skills were lacking, most notably assignments that required calculations, computer-aided design, and construction. In doing so, they sometimes failed to recognize that their weaknesses were not being improved, as can be seen in the following exchange:

Teammate A: I feel like that's the point of teamwork, is like whatever skill you have, that's what you should apply it to. So if [Teammate B] and I aren't too good at cutting or we can't build a certain thing, I feel like that's what [Teammate C] was useful for. And whereas [Teammate C] didn't really quite know how to calculate some of the math that went into it, that's where [Teammate B] and I came in. And I feel like that's what made our team a good team, like we were efficient and effective, but-
Teammate B: But then what happens when you get thrust into a group where none of us can cut, none of us can do that? Then you're screwed because you're like, "Well, I always had him who could do it."
Teammate A: That's true.
Teammate B: And so then you'll get that bad grade that you feel like isn't your fault.

When groups were assigned tasks such as worksheets, reports, and schematic drawings – items which could be completed by an individual – it was typical for one member from each team to complete the work, accepting responsibility for his or her teammates, yet depriving them of opportunities to gain the intended experience. By this practice, individuals were able to pass through the academy having learned very little in certain areas. Many of the students, for example, had little ability in computer-aided design. Others skirted any work related to math. Commenting on this issue, a student mentioned a math-based worksheet that was completed by just one member of his team. He said, "I think that once we fill out that center-of-mass form, I think the teacher just assumes that we all just know how to do it."

Another student found no issue with this situation, explaining, "I'm sure we could all go through it and explain it to each other if we needed to, but because the time we have and all the stuff we want to do in each class, we have to split up the roles." Many others shared similar thoughts, illustrating that students prioritized task completion over knowledge and skill development.

This lack of collaboration was not necessarily the intent of the students; it was sometimes simply due to physical limitations. For instance, it was essentially impossible for teammates to work together on computer-aided design drawings. Likewise, many course products were quite small, meaning that no more than one or two pairs of hands at a time could physically be involved in a project. The hovercraft course was unique in that, as several students noted, the sheer scale of the crafts allowed all teammates to work simultaneously. Even so, there were still limitations, an issue raised by a student who said, "I kind of feel like with these projects, like the smaller [prototype] hovercraft, there was always one of us sitting out because it just wasn't big enough for everyone to work on it. And sometimes with this one too [the full-scale craft], it's like you just need one person to hold the board in place and one person to like glue it down or whatever, staple-gun it." This type of situation further compelled students to delegate tasks.

Participation and collaboration assessment

"Do I feel like I could give them a grade that correctly assesses how much they've participated and how much they've helped their group? Yes. Do I feel like I have a good handle on that? Yes. Do I feel like I could justify their grade to their parents with actual physical evidence? No."
– Academy teacher

Participation typically accounted for about 10% of each student's grade in the academy. In the hovercraft course, it accounted for less than 6%. The teachers did consider increasing this percentage since it was viewed as a way to extrinsically motivate those in need of an extra push, but certain obstacles prevented this proposal from being implemented. Assessing participation was viewed as problematic, not in that teachers were completely unaware as to who worked diligently and who did not, but tracking the behavior of as many as thirty individuals was seen as "tedious." The teachers commonly pointed to the impracticality of participation assessments, particularly in project-based classrooms where supplies needed to be organized and dispersed, individuals required one-on-one instruction, and novel questions frequently popped up. Said one teacher, "I find myself getting too busy to monitor everyone's participation."

Yet a large number of students expressed a desire to be assessed more on their efforts. As compared to scores based on the performance of their crafts – which were often perceived as highly susceptible to uncontrollable circumstances – there was a general view that participation grades would have been a better representation of their work. The underlying reason such grades did not play a larger role the in the academy was due to their subjectiveness. According to the teachers, when participation grades were assigned, students – and their parents – viewed them as open for interpretation, leading to arguments and requests for proof. There was thus strong pressure to have clear justification for such grades. A teacher touched on this situation, commenting, "It's really hard for me to say this kid gets a ten, this kid gets an eight, this kid gets a seven. Even though in my mind I'm pretty sure that the grade that I'm giving them is the right grade, it would be hard for me to defend it."

Although the teachers acknowledged that explicitly noting reasons for docking participation points was possible, it would have required drastic oversight, ultimately inhibiting their abilities to facilitate classes. The cooperating teacher noted that assessing participation obliged her to focus on negative behavior, meaning that students who behaved well received less attention.

According to the cooperating teacher, collaboration was the most difficult learning goal to assess, a challenge with which all academy teachers struggled. Directly assessing students on this ability was seen as impractical because doing so would have necessitated time-intensive observation of each group as they worked through the design process. Just as important, students' interactions were often dependent on a teacher's proximity. One teacher pointed out these limitations, saying, "I can't listen in on every conversation that's happening throughout the room. And as soon as I get close, it actually changes the whole dynamics." Collaboration grades were therefore not issued in the academy.

Further complicating matters, a high level of participation did not necessarily equate to an equal level of collaboration. This situation was commonly found in groups with self-anointed leaders, those who controlled the direction of their groups' projects. A hovercraft team which made decent strides during the project, for example, was led by a highly-motivated student who worked tirelessly every class period. But he essentially ignored any input from his teammates. The cooperating teacher speculated that he had likely selected less-motivated teammates knowing that he would have free reign over the design decisions. Such students inhibited teachers' abilities to assign participation points since their go-it-alone attitudes alienated their teammates. A teacher provided an example of this situation, saying, ". . . the one student feels like she's doing everything and she's so frustrated with her team members because they're not doing anything. And then the team members come to me and say, 'She's not letting us do anything. She's such a control freak. Every time I try and do this, she gets mad and says, 'Just put it down! I'll do it!' . . . So do I grade him poorly for participation because he's been told not to participate? It's just difficult."

Group grades

"It was because of him honestly that I got the grade that I got in that class. I don't know, I guess there's no way that the teachers can monitor every little thing that everyone's doing, but I just think that sometimes that people benefit from others and they don't really deserve the grade that they should get. Because I know I did not deserve an A in that class, because all I did was like screw things in and make a poster, pretty much."

– Academy student, commenting on a previous course

Seventy percent of the grades assigned in the hovercraft course were based on group work, whereby members in each team earned identical scores, regardless of contribution. This reliance on group-based scoring was seen as a way to emphasize the importance of teamwork, a practice that had been implemented since the academy's inception. Administrators and teachers were somewhat indecisive on this issue, but they were generally not in favor of common group grades. The hovercraft teacher was one of the few who preferred the group scoring policy, though she did acknowledge "It's not a perfect system" because she was unable to penalize or reward individuals for their contributions. She confessed, "When it comes down though to, say it was like a really good project, really good job. Two good students and one slacker, like one person who clearly wasn't doing anything, I don't know what to do there."

More students were in favor of individualized grades than not, but not by a large margin. Not surprisingly, higher-achieving students tended to oppose group grades. The most common explanation was based on fairness, with many making points similar to a student who wrote, "I think it is not very fair because there is always someone that will contribute to the project more than another group member and they should be rewarded for that." Yet others argued that group grades supported authenticity in the classroom, such as the student who explained, "And so I think we all should get the same grade because we all do different jobs. They might not be the same or take the same skills, but that's more how it would reflect in real life, I'd assume, because everyone would work in a group and you would just work to your strengths."

This assessment strategy resulted in misalignment between contributions and grades. As one teacher put it, group grades did not "show us what their level of engagement is with the project." Consequently, there was a general lack of effort among students willing to 'hitchhike' on the labors of teammates, a downside readily observed by the cooperating teacher, who noted, "Especially if you start talking about the particular members of a group, it could be very much the case that one of three students really knows what they're doing and the rest, kind of just hanging out."

The teachers perceived hitchhiking as an enormously negative effect on the learning environment, particularly since "middle-ground" students could get "sucked in" to the less-than-ideal behavior, as the cooperating teacher mentioned. To address the situation, the teachers viewed more individual assignments as a necessary change.

Individual accountability

"If you could actually get that individual piece accurately and get an accurate representation of what did that person contribute to that final project, ideas versus building versus knowledge and understanding of it, I mean that should their whole grade. . . . It's just so difficult to get that – an accurate representation of what that person contributed."

– Academy teacher

Increasing the amount individual work was an idea put forth by seven of the nine teachers and administrators. Not only was this viewed as a way to improve accountability, but as a means to improve student behavior (see Table 3). Explained one teacher, "I know that they would know more if we did that. They would be a lot more serious about the class."

Table 3: Categorized results from teacher interviews – Participation & Individual accountability				
Comments about participation			Comments about individual accountability	
Topic	# Teachers		Topic	# Teachers
Many students not trying	5 (max = 5)		Can't assess individuals	4 (max = 5)
Difficult to assess	4		No ownership of grade/project	4
Poor behavior is an issue	3		Individual work = accountability	4
Can't motivate students	3		Need more individual work	3
Grades focus on poor behavior	3		Tests would lead to accountability	3

Four of the teachers noted that students lacked ownership of their work, pointing to the group grading structure as the catalyst for such attitudes. The students' actions supported this theory, as it was not uncommon for individuals to lack basic information about their own crafts. For example, when the question "What skirt depth did your team design for?" was informally posed to a member of each of the thirteen groups during class time, eight individuals were unable to answer and deferred to teammates, revealing that they were likely not fully active members in their respective group's design processes.

The cooperating teacher went as far as saying that she believed the students did not feel responsible for their own grades, a judgment put forth by two of her colleagues, leading them to fault teammates when problems arose. She said, ". . . they're also quick to blame their group if they haven't done as well as they wanted to, regardless of whether they chose their group or not. Or not even blame each other, but just blame the project."

Despite the nearly universal view that more individual assignments and tests would improve the learning environment, there was reluctance to include such measures due to the attention placed on inclusiveness. The teachers frequently expressed beliefs that reaching out to all students with interests in STEM fields was highly important, and traditional assessments were seen to be in conflict with this goal. But understanding the reality of the classroom situation, they were torn on this issue, as illustrated by one teacher's comments: "Sometimes that increased attention encourages them not to continue, which is not a good thing. But for some of them, this is not the right place for them."

Among the students, there was a common feeling that the classroom teacher needed to take on a more prominent role overseeing classroom actions so that grades would more accurately reflect individual work. Two administrators spoke on this topic as well, noting that acute teacher involvement was necessary to gain awareness of individual contributions and to foster accountability. For example, one explained, "I just think that it's a matter of checking for progress more often and having one-on-one discussions with team members. So if I pulled you aside and I say, 'Well, what's your responsibilities? What are you doing within the group?' . . . I think that's the part that will keep kids honest." While such actions align well with formative methods, the logistics of carrying out such measures for summative purposes were immense since this would require one-on-one discussions within already hectic environments.

Attempts to incorporate self- and peer-evaluations, viewed as means to gain more insight into individual contributions, were met with setbacks as well. Student responses, particularly from low-achievers, were quite often disingenuous, and little value was placed on these reporting methods. Dealing with parents was another area of concern. One teacher explained, "I feel like the parental component of that, when parents think that you have a kid giving my kid a grade, that's not cool. That's a big obstacle. And then there's also, you know, 'I just hate you, and we got put on a team together but I'm going to do everything in my power to make your life miserable.'" Recalled another, "The peer-assessment, I tried that one time. You know, rate your group members. And then had a parent go ballistic about 'How can kids grade other kids?'" Such measures were therefore virtually nonexistent.

Findings

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

By utilizing the project-based model, the academy provided an environment accessible to a wide swath of the school's population. Hands-on work, the key motivational tool for engaging students in the coursework, provided positive experiences in engineering. During the construction phase of the project, many students began working before the bell rang and remained active throughout the ninety-minute periods without need for teacher encouragement. Unsurprisingly, when asked to list recommendations for future course offerings, the most common response was for more build time.

Regardless of the students' initial intentions for joining the academy, hands-on work quickly came to dominate their expectations. While the construction of physical projects undoubtedly retained students in the program, for some, this was the *only* reason to remain. At the same time, the hands-on work was known to deter others, commonly those expecting more math and science content. It is therefore arguable that an overemphasis of such coursework can turn away potential future engineers who prefer more abstract learning.

Fifty-five percent of the course's class time was devoted to team-based activities, whereas just twenty percent was allocated to individual work (the rest being instructions, lectures, videos, etc.). Group tasks were well received by the students, who overwhelmingly enjoyed working with classmates. Importantly, they realized the importance of group work, viewing collaboration as a critical skill and one that led to improved projects.

Research question #2: What obstacles prevented expected achievement?

The use of group grades played an enormous role in the classroom. Since grades did not accurately represent individual efforts, the teacher was unable to foster student engagement by means of the assessment structure. Some students chose to exploit this loophole by skirting responsibility, taking little ownership of their work. This also inclined some to place blame elsewhere when their projects failed to function as expected. Further diminishing the team-based atmosphere were individuals who took over the majority of their groups' tasks, due either to unmotivated teammates or their own need for control.

Students did not always gain the intended collaborative experience since task delegation was a highly-prized strategy for workload reduction. And, by only working in areas of their own strengths, students often failed to improve their weaknesses. It is thus important that the students see proper collaboration modeled, with an emphasis placed on the process of working with others rather than on efficient task completion.

Though students of significantly different competencies participated in the course, a lack of ability was not perceived as a point of weakness. Indeed, several high-performing students declared that simply trying was sufficient. On the other hand, those who failed to work hard were viewed as detrimental to the classroom environment, and some students recommended altering the academy application requirements "to make the STEM program more selective as a program instead of allowing anyone to get in. This will create a more focused atmosphere among the STEM students," as one such student wrote.

In order to assess the students in an authentic manner, it was necessary to evaluate individuals' contributions in the classroom and their abilities to communicate effectively with their teammates, measures that would have aided in accountability as well. Yet doing so on a frequent basis was seen as completely impractical due to the innate difficulty of assessing participation and collaboration, as well as due to a need to provide justification for each student's grade in these areas, perceived as highly subjective measures.

Research question #3: What tensions were generated?

Individual assignments were seen as a means to improve accountability, but the inclusive nature of the academy prevented the teachers from relying more on such measures, as it was believed that doing so would have led to less retention. While it was admirable to reach out to commonly underserved student populations, the approach resulted in a substantial number of uncommitted students, those in the academy for reasons other than interests in STEM-related fields, and who often disrupted the learning environment.

The lure of implementing authentic assessments in the academy was well-founded, but basing students' grades largely on the functionality of their hovercrafts and their abilities to explain their design process yielded unexpected consequences. Most significantly, by highlighting course projects, the students became accustomed to focusing solely on performance, often disregarding the importance of learning goals the devices were intended to support. In addition, because students were not required to explicitly demonstrate their understandings by means of traditional assessments, nor were they held to high standards with regards to the manner in which they worked through the engineering design process, they tended to view the academy courses as quite undemanding, which further encouraged students to trivialize their own efforts. The crux of the matter, therefore, was that the autonomy provided in the classroom allowed highly-engaged students to flourish, but at the same time, those without motivation persisted. In order to keep these latter students on task, more oversight would be required, yet by doing so, authenticity would resultantly diminish.

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