Impact of Various Pedagogies on Design Confidence, Motivation, and Anxiety of First-Year Engineering Students

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Introduction

The content and pedagogies of first-year engineering programs vary widely from institution to institution. In the content space, efforts are underway to establish a first-year body of knowledge [1][13][14]. While this effort is still far from complete, initial findings indicate that most such programs include some degree of engineering design.

In terms of pedagogy, a movement has been underway towards the flipped classroom. A flipped, or inverted, classroom is defined succinctly by Lage et al.: "Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (10, p.32). While this definition seems to imply a simple reversing of the traditional in-class and out-of-class activities, the practical application has opened up significant opportunities for new pedagogical methods. Most commonly, the flipped classroom label refers to an assortment of web-based video lectures, online modules, or quizzes completed as pre- and/or post-lecture homework coupled with interactive group learning activities taking place inside the classroom. These in-class activities include cooperative learning, collaborative learning, peer-to-peer learning, problem-based learning, small group discussions, question and answer periods, and the broadly defined active learning [1][16]. Active learning is broadly defined by Prince as "any instructional method that engages students in the learning process." Prince goes on to note that, in the common usage, this definition is further confined to those activities which occur inside the classroom and which are collaborative, cooperative, or problem-based activities [12]. These active techniques have been previously shown to enhance student engagement, cognition, and performance [7][16]. For additional depth of study, the reviews of Bishop [2] and Prince [12] provide good summaries of the various methods and their documented impact.

In the first-year engineering space, a number of institutions have adopted various degrees of the flipped classroom model. The focus on design thinking and problem solving in first-year engineering programs makes them particularly well suited to a flipped approach. Daher and Loehring noted that, while the flipped model they adopted required students to take greater responsibility for their own learning, course evaluations indicated that students did not find the flipped course to be any more work than previous iterations [4]. Researchers at Rowan University used a Pathfinder ebook and online exercises and reported a positive response from both students and faculty, especially in terms of the immediacy of feedback provided by the online system [6]. The Ohio State University used a set of videos, readings, and online quizzes as out-of-class preparation activities, coupled with an in-class application phase consisting of a short review lecture followed by in-class activities and assignment work time. They noted, with some surprise, that students appeared to prefer the quizzes over other flipped content. Further, students were very polarized in their like or dislike of videos versus readings, with clear separation between groups preferring one over the other [11]. Schluterman implemented a flipped model at the University of Arkansas and noted that students had a slight preference for video lectures over in-class lectures [17]. Saterback provides a detailed analysis of the impacts of a flipped model on student achievement of course outcomes and notes little difference between a partially flipped and fully flipped model [16].

In summary, the use of a flipped classroom model in first-year engineering design courses is widespread. However, the majority of analysis has focused on student achievement of outcomes or, in many cases, on student preferences and usage of online resources. It has been proposed that flipped classroom methods lead to greater levels of both intrinsic and extrinsic motivation by satisfying student needs for competence, autonomy, and relatedness [1]. This study seeks to examine the following research question:

What is the impact of various pedagogies deployed in an introduction to engineering course?

Impact in this case is evaluated using survey of student perceptions about the course materials (a measure of the impact on student experience) and regular surveys of student design confidence, motivation, anxiety, and expectations for success (a measure of the impact on student learning).

Setting and Context

Ohio Northern University is a small private university in the Midwest with a total enrollment of around 3,500 students. The T.J. Smull College of Engineering is home to six programs – Mechanical, Civil, Electrical, and Computer Engineering, Computer Science, and Engineering Education. The student population includes international and underrepresented minority students, but is largely made up of those from small, rural, Midwestern towns. The study population, consisting of first-semester engineering students, is approximately 86% male to 14% female. Just under half (48%) reported having some engineering design content experience prior to enrolling in the course.

The first-year engineering experience at ONU consists of three courses – a two-course introduction to engineering sequence and a department-specific orientation course. Both introductory courses are three credit hours while the orientation is a zero-credit-hour pass-fail course. All first-year students in the college except Computer Science students are required to take both introductory courses. This work focuses on the first of the introductory courses. In the time period under study, students were enrolled in four sections of approximately 30 students each. Each section met for three 50-minute class periods per week. The instructional team consisted of three faculty members.

The course provides a broad introduction to engineering topics, including design, analysis, and communication. The outcomes of the course are 1) Apply design thinking to solve engineering problems, 2) Apply engineering tools and skills to perform engineering analysis and design, 3) Apply a basic understanding of mathematics principles in an engineering context, 4) Use effective communication tools to convey information to a target audience, and 5) Begin to develop the personal and professional mindset necessary for success as a practicing engineer. The full details of the content included in the course have been previously presented [9]. Each stage of the design process is explored in depth, each with its own progression of content. In the current study, this progression generally follows the structure of 1) pre-lecture interactive online module, 2) in-class content review via brief lecture, 3) in-class active learning via group work, 4) individual homework, and, as a culminating experience, 5) the relevant component of a semester-long team design project. The details of the online modules, in-class activities, homework, and semester-long design project are included below for additional context.

Pre-Lecture Online Modules

Interactive online modules were developed using Articulate Storyline 2 and embedded into Moodle [18]. Each module was designed around a single topic, such as a particular phase of the design process.

Modules were assigned to students and included a mix of reading, instructor voice-over, and interactive activities (e.g., matching, click-and-drag, and simple click-and-explore activities). Example interfaces for one module are shown in Figure 1. The modules were designed to take students 10-20 minutes to complete and were made available for review at any time.

Figure 1 – Example interfaces from interactive online modules

In Class Active Learning

In an effort to expose the students to a greater variety of engineering-related disciplines and practices, to compel them to work directly with more of their classmates, and to provide them an opportunity to engage with individual steps of the engineering design process, short-term in class activities were included in the curriculum. These activities ranged in complexity and time scale, from single- or partial-lecture activities to longer, multi-lecture mini-projects.

In all cases the activities were situated in an open-ended, authentic context and intended to provide an experiential interaction with the content being introduced. For example, while introducing the problem definition phase of the design cycle, students were asked to work with a team to perform problem definition. They were prompted to consider the problem of designing a robot which could construct habitats on Mars. Over the course of a class period, teams worked to define the need, stakeholders, direct users, and project goals, each step intermixed with a brief review of the corresponding content from the pre-lecture module. In a second class period they were asked to expand their work to include criteria and constraints, again intermixed with a corresponding content review. Teams then developed a poster communicating all of the above and presented their work to the class via a gallery walk. No direct assessment was done on the work, leaving assessment of the covered content for homework, exams, and the semester project.

A more involved example, a two-week buoyancy project inspired by a more in-depth project by Goodrich and McWilliams [8], tasked the students with mathematically modeling a conceptual design before physically evaluating its performance. In addition, the project incorporated a number of key concepts (e.g., independent vs. dependent variables, uncertainty in measurements, significant figures, developing an experimental test plan) that had been taught in a lecture format in previous iterations of the course.

Like many of the course assignments, the buoyancy project was authentically situated – in this case, an environmental group requested assistance with the design of a Sustainable, reConfigurable, Aquatic Living Environment (SCALE), which consisted of five modular "pods" that were to be placed upon the deck of a floating structure. To satisfy the request, teams of 3 to 4 students were tasked with creating an affordable, small-scale prototype of the structure with minimal environmental impact (15 different basic materials were available for "purchase," each with an associated cost and impact to the environment). Before constructing their prototypes, the students were expected to utilize presented mathematical concepts related to buoyancy and moments in order to predict physical results (the environmental group requested the structure's deck height be stable and 1" above the surface of the water). Importantly, the teams were not permitted to use a guess-and-check method to fine-tune their prototypes, a common practice in project-based engineering coursework. In addition to the SCALE prototype, teams submitted two brief memos outlining their designs and detailing their equations and calculations. See Figure 2 for example prototypes.
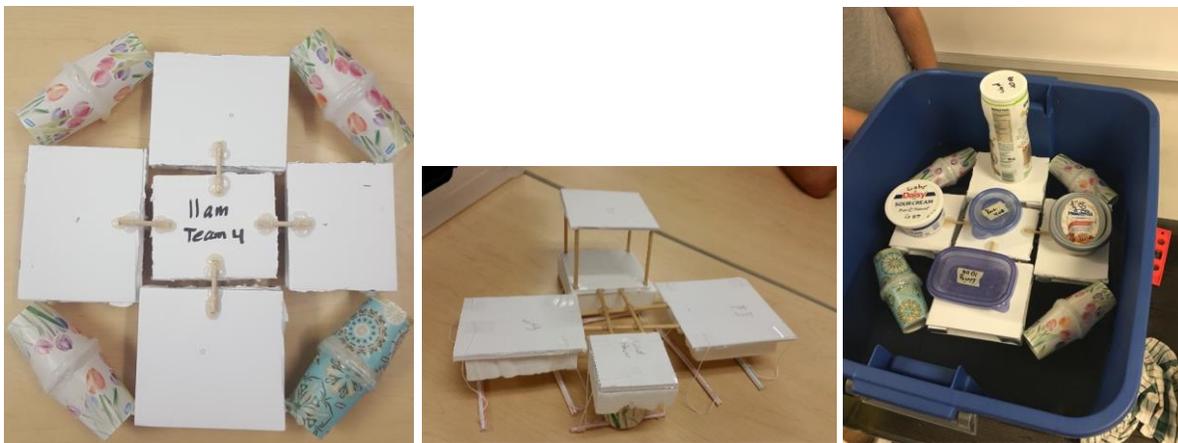

Figure 2 – Sample buoyancy project prototypes

Homework

Homework was completed individually on an approximately bi-weekly schedule, with each assignment consisting of a series of short questions including short answer, multiple choice, fill-in-the-blank, etc. For example, one question covering problem definition presented students with the following prompt:

> *Your company has a contract to develop a backpack that will be competitive in today's market. It may have whatever features you choose, but should be appropriately specified and priced accordingly.*

Students were then asked to identify the need, list stakeholders, and identify criteria and constraints. This assignment was given after the problem definition in class activity discussed in the above section and was similar to interactive examples provided in the corresponding online module. This allowed students to perform similar tasks in lower-stakes environments before being asked to perform (and be assessed).

Semester Project

The central project for the course was the design and presentation of a projectile motion device. Inspired by a project by Roszelle [15], the projectile motion device served as both a vehicle for developing students' engineering skill-sets and engaging them in the application of the design process. While the majority of project work took place outside of class, in class instructors led lessons and activities designed to emphasize the critical aspects of the design process, including identifying the problem, generating and reducing design concepts, modeling and evaluating a design, and communicating results. In parallel, students were responsible for completing individual assignments to develop their skills in areas such as basic fabrication, composing and facilitating experimental tests, utilizing spreadsheets and modeling collected data, and delivering presentations. These skill-building activities were intended to directly support the students' abilities to satisfactorily complete the projectile motion project.

The projectile motion project began with a mock request by a children's museum, which has plans to develop a new exhibit to support STEM education. Specifically, the museum requested a prototype that 1) highlighted the principles of projectile motion, 2) demonstrated basic engineering mechanisms, 3) encouraged scientific exploration, and 4) inspired the spirit of creativity. The prototype was expected to be supported with CAD drawings, a design report and presentation, and an associated exhibit display poster. The students, again working in teams of 3 to 4 individuals, were required to progress through a series of "milestones" to bring a selected design concept to fruition. Rather than solely focusing on the physical performance of their final prototypes, teams were evaluated on their ability to follow the design process and communicate their rationale for the decisions they made; it was expected that they used their research findings, collected data, and gathered feedback to justify their design decisions. By the end of the semester, each team was responsible for presenting a finished working prototype along with a design report detailing their prototype's physical and performance characteristics; they were also required to present their finished products to an outside audience. Example prototypes are shown in Figure 3.

Figure 3 – Sample projectile motion project prototypes

Data Collection and Analysis

In order to assess student attitudes towards design, a valid and reliable tool developed by Carberry and Ohland was used [3]. This tool uses a series of 10-point scale items to assess student confidence, motivation, expectations of success, and anxiety in performing each of several design tasks. The answer choices are presented on a 0-100 scale because that same scale was used in the source study but, in

order to reduce the difficulty for survey takers, only 10-point increments were selectable. Question prompts are outlined in Figure 4. The list of design tasks examined is included as Figure 5. A baseline survey of all tasks was administered at the beginning of the semester. Partial check-in surveys were administered at two points during the semester – after completion of the problem definition phase and again after completion of the concept generation, concept reduction, prototype construction, and prototype testing phases. These surveys included only a subset of tasks, covering the relevant phases of the design cycle. A final post survey was conducted after the conclusion of the semester and covered all tasks. All surveys were collected anonymously. The pedagogies discussed above were utilized throughout the semester and covered all tasks surveyed.

Table 1 - Design Survey Items, taken from [3]

Rate your degree of confidence (i.e. belief in your current ability) to perform the following tasks by adjusting the slider to a number from 0 to 100. (0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)
Rate how motivated you would be to perform the following tasks by adjusting the slider to a number from 0 to 100. (0 = not motivated; 50 = moderately motivated; 100 = highly motivated)
Rate how successful you would be in performing the following tasks by adjusting the slider to a number from 0 to 100. (0 = cannot expect success at all; 50 = moderately expect success; 100 = highly certain of success)
Rate your degree of anxiety (how apprehensive you would be) in performing the following tasks by adjusting the slider to a number from 0 to 100. (0 = not anxious at all; 50 = moderately anxious; 100 = highly anxious)

Table 2 – Design Survey Tasks, adapted from [3]

Conduct an engineering design	Identify a design need	Identify a design stakeholder
Identify a design attribute	Identify a design constraint	Identify a design criterion
Research a design attribute, constraint, or criterion	Develop design solutions	Select the best possible design
Construct a prototype	Evaluate and test a design	Communicate a design
	Perform a redesign	

Discussion of Survey Results

Aggregated data from the four assessments of student confidence, motivation, expectations for success, and anxiety is presented in Figure 4. This figure shows a standard box-and-whisker plot of student data on each survey task for each of the four surveys administered. Note that the second and third surveys included only a partial set of design tasks, meaning that not all tasks have data from all four surveys. Mean student responses to each question are also included as Table 3 with a summary of total change in mean response included as Table 4. Student confidence saw the greatest gains across all topic areas, with the most substantial impact seen at the lower end of the spectrum. Motivation was largely unchanged throughout the semester, but picked up slight gains in the post-survey. Student expectations for success saw a lesser increase than confidence, but still broadly spread across topics and most significant for students at the lower end of the distribution. Student anxiety was largely unchanged across the board. Overall, these are viewed as positive results, especially the boost to student confidence. In addition, baseline survey results are in line with the original results obtained by Carberry et al. for their Intermediate experience group, while intermediary and post survey results indicate a shift to more closely align with the original study's high experience group [3]. These terms, as used by Carberry et al., were defined based only on survey responses, to stratify the responses; the total study population included engineering professors and practitioners, graduate and undergraduate students, and non-engineers. In this context, a population of first-semester undergraduates scoring in the

intermediary category is surprising. To some degree, this may be the result of roughly half (49 of 106) of respondents in this work indicating some degree of prior engineering experience through programs such as Project Lead the Way. It is also unexpected but encouraging to see students moving from a profile consistent with an intermediate experience level to one of high experience within the bounds of a single semester.
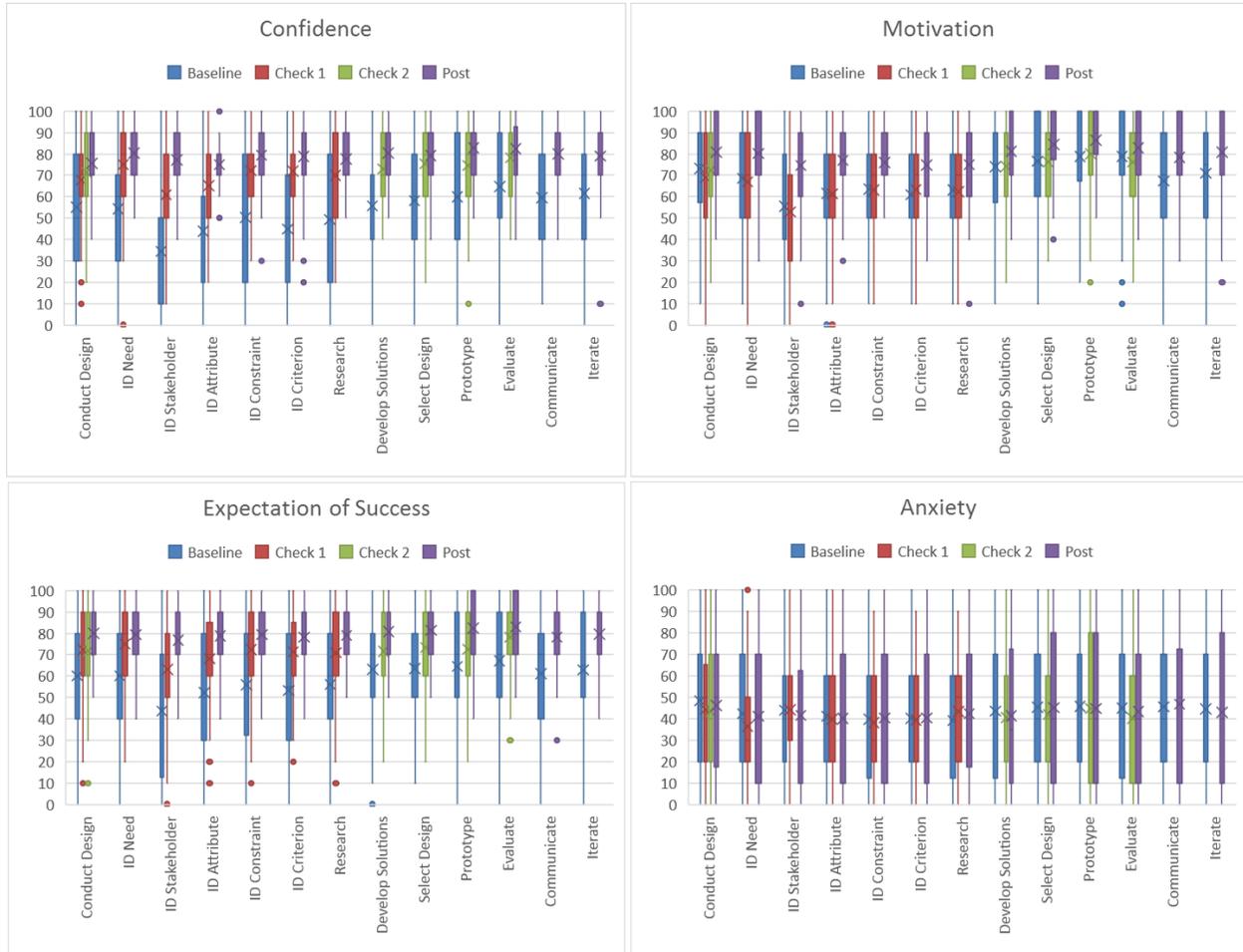

Figure 4 – Data distributions from student surveys

Table 3 – Mean student responses to survey questions

Survey	Conduct Design				ID Need			ID Stakeholder			ID Attribue			ID Constraint			ID Criterion		
	Base	Chk1	Chk2	Post	Base	Chk1	Post	Base	Chk1	Post	Base	Chk1	Post	Base	Chk1	Post	Base	Chk1	Post
Confidence	55	68	71	76	54	75	80	34	61	77	44	65	75	50	72	79	45	72	79
Motivation	73	69	72	81	68	67	80	56	53	75	62	61	77	64	63	76	61	63	75
Exp Success	60	72	72	80	60	75	79	44	63	77	53	68	79	56	72	79	53	71	78
Anxiety	48	44	43	46	42	36	41	44	44	42	41	40	40	40	38	40	40	39	40
	Research			Develop			Select Design			Construct			Eval & Test			Comm		Redesign	
Survey	Base	Chk1	Post	Base	Chk2	Post	Base	Chk2	Post	Base	Chk2	Post	Base	Chk2	Post	Base	Post	Base	Post
Confidence	49	70	78	56	73	80	58	75	79	60	75	83	65	78	82	59	80	62	79
Motivation	63	62	75	74	74	81	77	76	84	79	80	86	79	76	83	67	78	71	81
Exp Success	56	71	79	63	72	81	63	73	81	65	73	82	67	78	83	61	78	63	80
Anxiety	39	43	42	44	41	41	45	42	45	46	45	45	45	40	43	46	47	45	43

Table 4 – Total change in mean student responses to survey questions

	Confidence	Motivation	Exp Success	Anxiety
Conduct Design	20.5	7.8	19.8	-2.2
ID Need	26.1	11.8	19.1	-1.2
ID Stakeholder	42.8	19.0	33.0	-2.3
ID Attribue	31.2	15.5	26.2	-1.0
ID Constraint	29.1	12.3	23.3	0.6
ID Criterion	34.0	13.9	24.8	0.2
Research	6.4	11.9	22.7	3.2
Develop	24.8	7.2	17.7	-2.2
Select Design	21.1	7.7	18.0	-0.2
Construct	23.0	7.6	17.7	-0.9
Eval & Test	17.8	4.0	15.9	-1.6
Comm	20.6	11.2	17.1	1.1
Redesign	8.0	10.0	16.7	-1.5

In addition, a survey of students was administered in one section of the course to assess student perceptions of the various course materials. In-class activities, such as discussed previously, were clearly identified as a crowd favorite. Homework in the traditional sense was identified as the least useful, albeit to a lesser extreme. Students were generally mixed in their views of the semester project, with some wishing they were evaluated more as an individual and others recognizing the value of the team-based work. Student perceptions of the online modules and lecture slides were largely identical and in both cases slightly positive. These results are largely in line with what was expected based on the review of literature and are detailed in Figure 5.
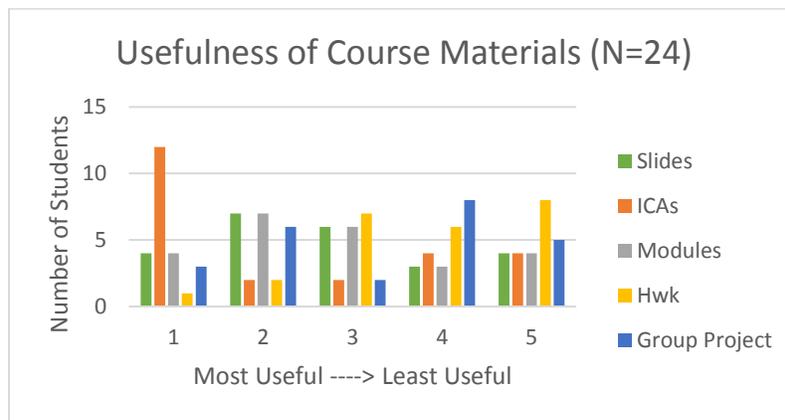

Figure 5 – Usefulness of course materials, per student feedback

Discussion of Activities

The online modules were perceived by instructors as a great benefit, in that they freed up valuable class time for more engaging activities (as noted by both instructors and students). Concerns were expressed with respect to student understanding of the material covered through some of the online modules, though it is not clear whether this was the fault of the medium or simply the difficulty of the content. It was generally observed that students tended to rush through the online content and ultimately come away with a general but incomplete understanding. This indicates that, at least for first-year students with less academic self-discipline, online modules are suited for a broad introduction to a topic or reinforcement of content delivered elsewise but not to more detailed content delivery. Generally stated,

while the online modules were beneficial in that they enabled in-class time to be spent on other activities, caution is advised in the depth and degree to which lasting content comprehension is expected to occur without additional touch points.

The smaller buoyancy project was challenging in that it presented a significant investment of time and was calibrated with expectations perhaps beyond the capabilities of the students. These challenges obscured the goal of the project and hindered achievement of the learning objectives for the unit. In particular, the mathematical modeling element of the project presented significant challenges for the students due in part to students lacking the background understanding needed to grasp the necessary elements of the model. As is common in first-year programs, balancing the time-expenditure required to introduce supplementary content unrelated to core course objectives (e.g., buoyancy equations) and developing sufficiently authentic and engaging activities remains a challenge. Students did engage with and respond positively to the design-build-test element of the project and appreciated the practical application. The project was largely viewed as a success but in need of significant revision to improve achievement of stated objectives.

The primary course project, on projectile motion, was very well received as an engaging opportunity to develop applied skills in an engineering context. The time required by the project, both for students and instructors, was significant but generally viewed as valuable. Group dynamics continue to be a friction point, as expected for first-semester students. From an instructional standpoint, tying so much of the course to the semester project created additional difficulty in assessing individual understanding. In terms of student performance, developing a properly scoped problem, especially with respect to generation of criteria and constraints, was a concern. Regarding creativity, many teams incorporated very basic design features (e.g., a spring) to ensure their prototypes worked rather than seek out innovative, yet untested, design concepts (this commonly occurred even though prototype performance represented less than 5% of the total grade); to mitigate this unwanted approach, it is suggested that targeted instruction and emphasis on acceptance of failure be included in the project. None of the above issues, however, are unique to this project or course but rather challenges of the first-year space and group projects in general.

Limitations

One limitation of this study is that there is no control for comparison, beyond that provided in the literature. Because of this limitation, conclusions may be drawn broadly about the course but isolating the impacts of specific activities is difficult. For a more conclusive result, a similar study should be run with parallel populations. Additionally, the fact that survey data was not collected in an identifiable format makes tracking of student development on an individual basis impossible. Such capability would have added an additional dimension for analysis of these results with respect to factors such as pre-college preparation and student demographics.

Conclusions

Online modules, in class activities, and a longer project were all implemented in a first-year engineering course. The details of the modules, in class activities (including short- and long-form activities), homework, and the semester project (projectile motion project) were detailed. Instructor commentary was also provided with respect to each activity type. Broadly speaking, the activities were well received but presented additional challenges. In the case of online modules, it is suggested that the format be

used only for broad introductory material rather than substantial content delivery. However, the modules did enable ample in-class time to be devoted to more engaging activities and, for this reason, is viewed as a valuable component of the course. The in class activities were also well received, although in the current form there were concerns with some activities about difficulty and the necessity for providing students with additional background content. This too was seen as a surmountable challenge and similar projects are recommended for future use. The longer project brought significant challenges in the form of individual assessment and time/effort burden. As long as sufficient mechanisms are in place to mitigate these concerns, developing the course around a central project is a positive change.

A series of surveys were conducted throughout the semester to evaluate student confidence, motivation, expectations for success, and anxiety towards several design tasks. It is difficult to ascertain whether the design survey results are directly the result of particular instructional methods, but broadly speaking changes in student attitudes compare favorably to changes observed in the literature using similar assessment tools. The clearly positive improvement on several fronts warrants further and more rigorous exploration. Anecdotally, student feedback was largely positive with respect to the new methods, as compared to more traditional lectures. Even if the design attitude impact of the pedagogies remains to be proven, with positive student reception and a general positive reflection on the part of participating faculty members, this is a very encouraging result.

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