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Implementing First-Year Design Projects with the Power of Choice

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Implementing First-Year Design Projects with the Power of Choice

Abstract: This paper presents the re-design of an introduction to engineering lab course at a private urban institution in the Midwest. In the lab portion of the course students were provided with a menu of three design projects, asked to rate their interest in the three projects, and split into small teams according to these ratings. In a given semester the three projects centered on a theme such as water balloon launching technology or small vehicle technology. The average interest rating for all projects was rated as 3.58-3.65 on a 1-5 Likert scale while the average interest rating of the project that each student actually worked on was rated as 4.61-4.8. It is concluded that by simply offering a few choices students will be able to work on a project in which they have significantly more interest. This paper further discusses some of the important effects that choice can have. Follow-up student survey results reveal that students do feel that it is important that course material overlaps with their interests (4.34 Likert rating) while their typical courses only marginally overlap with their interests (3.07 Likert rating). This paper also provides an overview of the various projects, detailed results from the student ratings, and survey results used to gauge how well the project menu appealed to students' interests.

Introduction

Coming into college many first year students may only have an incomplete sense for what an engineer does. In the process of helping them gain a better understanding of engineering it is critical to keep the students engaged and interested so as to facilitate retention. These objectives can be difficult to satisfy simultaneously as the material and projects are typically dictated by the instructor who simply cannot appeal to the interests of all the students with a single activity.

Laboratory components to engineering courses help to engage students and are valuable for providing students hands-on experiences. These labs demonstrate principles learned during lecture and develop basic experimental, measurement, and fabrication skills. There are many types of lab experiences such as demonstrations, field trips, "cookbook" type experiments, guided inquiry exercises, and design, build, test (DBT) projects [1, 2, 3, 4] each of which can promote different educational goals.

In a DBT project students learn the complications and compromises engineers must face while trying to convert an idea into a reality during the design and build phases. The testing phase provides concrete feedback on how well a design functions and exposes errors in the judgments and processes used during the previous phases. Use of a DBT project in a first-year introduction to engineering course has a number of benefits, one of which is getting experience working in a team and meeting classmates. Students further benefit by dealing with an open-ended problem early on in their studies, and approaching problems for which they do not have complete information nor when there is a single correct answer as is commonly the case with engineering.

Finally, these projects can serve to help students realize the importance of time management and dedicating time for redesign as it is rare that the first design ends up being the final one.

In this study students in a 1 credit first-year introduction to engineering class were presented with 3 DBT projects. Before the projects began, the students were presented with three different projects and asked to rate their interest from 1-5 on a Likert scale (1 = very disinterested, 5 = very interested). Based on their interests, students were then split into teams of 3-4 students to work on one of the three separate projects. By determining the students' teams and projects in such a manner, the students effectively were able to choose which project they worked on. It is worth noting that this class had a single 100 minute lecture and 100 minute lab each week, for a 14 week semester and that 5 consecutive lab periods each semester were dedicated to the DBT projects described in this paper.

The inclusion of choice in projects or assignments has been previously shown to have significant impact on outcomes. Perhaps the most encompassing reference examining the effects of choice is that of Patall, Cooper and Robinson[5] which is a meta-analysis of 41 different studies. The avenues through which choice have an effect stem from self-determination theory which stipulates that people have higher intrinsic motivation for tasks which promote their personal autonomy, learning and mastery of a topic, and help create a sense of belongingness with others. Accordingly, by providing choice in a task a person will have an enhanced experience of autonomy which has multiple benefits. Patall, Cooper and Robinson reveal that providing choice can result in an increase in: sense of personal control, motivation, interest in a task, liking of a task, effort, performance, learning and perceived competence. Though it is further discussed that all choices do not elicit the same effect on people and in certain situations the ability to make a choice on a task can have a detrimental effect, particularly if there are too few or too many options to choose from or if the participants see the choices as unimportant or irrelevant. It is concluded that providing 3-5 options from which to choose is typically most optimal[5], and that as more choices are presented people can start to become overwhelmed, thus reducing the positive effects of providing choice. It is further concluded that the strength of the effects of choice can also depend on culture and gender with the effects being strongest in Caucasians and somewhat stronger in females compared to males.

Patall, Cooper and Wynn[6] further examined how choice affects student autonomy. In this study the authors discuss that a student's sense of autonomy can be promoted, in addition to providing choice, by teachers who demonstrate the following behaviors: "listening carefully, gearing instruction to students' interests and personal preferences, expressing value for tasks and provide rationales for activities, using non-controlling language, providing opportunities for and responses to questions and comments, and acknowledging students perspectives." While these behaviors can help a student to feel a greater sense of autonomy they are more subtle and the authors suggest that providing students with choice is the most tangible method of communicating their autonomy. It was further concluded that giving choices in school may also stimulate students to perceive that they are receiving other forms of autonomous support from the instructor. This suggests that choice affects student autonomy in both a primary and secondary manner, thus increasing its impact on student motivation.

Despite the apparent benefits of choice for students, there can be obstacles when implementing it within engineering education. One example of this is the increase in work required by a teacher to build choices into their curriculum. Another is the fact that many courses have such a heavy amount of pre-determined theories, concepts, and mathematical tools that there is little time or space in the semester. Due to the nuanced nature of choice effect it seems that the field of engineering education will benefit from research on choice within collegiate level courses. One such study by Meadows, Fowler and Hildiner[7] has shown that student interest and perception in engineering increased when students explore topics aligned with the incoming interests.

This paper looks at how offering a choice in lab projects affects the interest rating of the project a student completes. Further, surveys were used to assess student attitudes towards the various projects and factors that affected their initial project interest and a discussion is provided which suggests how the current results fit in with past research on choice.

Project Overviews

All of the projects described in this paper were developed to force students to design around competing objectives, such as shooting a water balloon for distance and accuracy. These two objectives were combined to determine a performance grade for each project, and any single objective had a minimum threshold that needed be met in order to receive any points for performance. It is noted that design performance only accounts for a fraction of the project grade. The different projects and their performance criteria are described in this section and it is noted that one group of students was given a choice between three projects that involved different small vehicles while another group of students was given a choice between three different water balloon launcher technologies. The various projects completed by the students all had a few aspects which were identical regardless of which project was being completed:

- projects must be made from scratch; individual components such as wheels, fasteners, etc. may be purchased but the body must be built/shaped by the team
- projects must have at least one layer of safety built in to prevent injury to users/bystanders in a worst case scenario
- a safety report must be completed by all teams before any building or testing begins
- final performance testing was completed during lab after 5 weeks of dedicated lab time
- Grading breakdown: 25% for having a working design that meets constraints after 4 weeks, 25% for project performance, 25% for final report, 25% for group member assessment

Crash Car Design Project: The idea for this project came from Bart Johnson at Itasca Community College. In this project students build a small car to be launched three times via elastic bands towards a thick aluminum plate positioned 24 feet away. The design objective was to build a vehicle for speed and durability. Additional project constraints were:

- Vehicle can only be propelled forward by the elastic bands used for launching
- Vehicle must travel on the ground from launch to impact
- The launching mechanism cannot be altered in any manner and your vehicle must launch cleanly without damaging the launcher
- Between launch and impact the vehicle cannot be interfered with directly or remotely by any person
- Vehicle must be less than 24" long, less than 14" wide and must weigh between 1-5 lb_f
- Vehicles will be inspected for safety and any vehicle deemed unsafe will be disqualified
- No team can spend more than $30 on their project; free materials do not count towards the $30
- Teams cannot make repairs between the final testing launches; nothing can be added or removed from the vehicle between final testing launches
- The tension on the elastic launch bands is set by the instructor and will be the same for all teams
- Vehicle must stay on its wheels until impact

At the final testing each team's design was launched three times and a performance score was determined for each launch based on the vehicle speed and any damage that occurred. Vehicle speed was measured using a radar gun half way between the launcher and impact plate. Durability judgments were made by the instructor and student mentors. Students were told that cosmetic damage would include, but not be limited to, scratches, dents, cracks, inelastic material deformation and material failure which result from a test. Students were also told that functional vehicle damages would include wheel alignment, pieces dragging, aerodynamic degradation, and damage which impaired launching.

For an individual launch the overall performance score was determined by multiplying the speed score with the durability score, shown in Table 1. Thus, if a vehicle traveled at 26 mph and sustained no damage during a single trial it would receive a 3 x 5 = 15. If a vehicle's speed was lower than 13 mph it would receive a score of 0 regardless of whether there was any damage or not (0 x _ = 0). The total performance score was determined by summing the scores for the three final testing launches. Performance scores correlated to performance grades as shown in Table 2.

Table 1. Speed and durability score criteria for Crash Car project

Score	Speed criteria	Vehicle durability criteria
5	35 mph or greater	No visible or functional damage
4	30-34 mph	Light to medium cosmetic damage, no functional damage
3	25-29 mph	Heavy cosmetic damage and/or minor functional damage
2	20-24 mph	Small piece chipped off and/or medium functional damage
1	14-19 mph	Large piece broke off and/or significant functional damage
0	< 13 mph	Unable/unsafe to operate again

Table 2. Performance score relation to grade

Performance Grade	Total Performance Score
A	>30
B	25-30
C	20-24
D	15-19
F	<15

Payload Glider Design Project: The objective of this project was to build a glider which could carry a minimum payload while staying airborne for a few seconds. This project had the following additional constraints:

- Glider will be hand launched (thrown) by a member of your team
- Between launch and impact the glider cannot be interfered with directly or remotely by any person
- Vehicles will be tested in the classroom
- No team can spend more than $30 on their project; free materials not counted towards $30
- Teams can make repairs between the final testing launches and add or remove material
- All 3 test launches must be performed within a 10 minute time span, any launches outside of this time period will not be counted
- The payload is determined by the team (weight, shape, material, placement), may not provide any structural or aerodynamic benefit to the design, must be easily removable and must remain fixed to the glider for the duration of the flight

During the final testing the glider flight times were measured using a stopwatch and a scale measured the mass of the payload just prior to each flight. The final testing consisted of three flights, each of which received a score for how long the flight lasted and the amount of payload carried as shown in Table 3. These two scores were multiplied together to determine the performance score of the individual flight, and the scores for all three flights were summed to create the overall performance score. Table 2 was used to correlate the overall performance score to a grade.

Table 3. Flight time and payload score criteria for glider project

Score	flight criteria	Payload criteria
5	> 5 sec.	> 500g
4	4-5 sec.	375-500g
3	3-4 sec.	250-375g
2	2.25-3 sec.	175-250g
1	1.5-2.25 sec.	100-175g
0	< 1.5 sec.	< 100g

Potential Energy Vehicle Design Project: This project was inspired by the ASME H2Go competition, though water was not used. Its objective was to build a vehicle that would convert gravitational potential energy into the motion of a vehicle carrying a payload. This project had the following additional constraints:

- Vehicle can only be propelled forward by the 90 J of gravitational potential energy provided at the start of a test
- The decision of how much mass and its starting height is up to the team, though it must result in a gravitational potential energy not greater than 90 J
- At the start of a launch the instructor will release the weight from its starting height as instructed by a team; the weight will be in the form of weight lifting plates
- Your vehicle need not catch the weight which was dropped; this weight will not be counted as payload
- Teams may make an apparatus in additional to the vehicle which captures/converts the potential energy and delivers it to the vehicle
- The vehicle must be propelled, not pulled forward
- Upon launching the vehicle cannot be interfered with directly or remotely by any person
- Vehicles will be tested in the classroom
- Vehicles will be inspected for safety and any vehicle deemed unsafe will be disqualified
- No team can spend more than $30 on their project; free materials do not count towards the $30.
- Teams can make repairs between the final testing launches and add or remove material
- All 3 test launches must be performed within a 10 minute time span, any launches outside of this time period will not be counted.
- The payload is determined by the team (weight, shape, material, placement), may not provide any structural, propulsive, or aerodynamic benefit to the design and must be easily removable
- The payload may not drop vertically relative to the vehicle.
- Vehicle must start within 1” of the floor.

To determine the potential energy change the vertical change in the height of the weight plates' center of mass was used. Each design was launched three times and a performance score was determined for each launch by multiplying the distance score with the payload score as shown in Table 4. The overall performance score was taken as the sum of the three launches. A tape measure was used to determine the straight line distance traveled between the vehicle's initial and final positions and a scale was used to measure the payload prior to each test. Table 2 was used to correlate the overall performance score to a performance grade.

Table 4. Distance traveled and payload score criteria for potential energy vehicle project

Score	distance criteria	Payload criteria
5	> 30 ft.	> 2000g
4	25-30 ft.	1500-2000g
3	20-25 ft.	1000-1500g
2	15-20 ft.	750-1000g
1	10-15 ft.	500-750g
0	< 10 ft.	< 500 g

Water Balloon Launcher Projects: Whereas the vehicle projects were all very different from each other in terms of objective, the various projectile projects had identical objectives which were to design, build and test a remotely triggered water balloon launcher for distance, accuracy, and consistency. The projects varied in the technology used to launch the water balloon and students could rank their interest in working on a catapult, trebuchet, or compressed air cannon. Each project had identical constraints:

- Launchers must have at least 3 layers of safety
- Launcher must be remotely launched from a distance of at least 8 ft.
- Budget of $100 per project; students may use free materials which will not count towards the $100, but their cost must be included in the bill of materials.
- Only the water balloons provided may be used, teams are responsible for filling them to the desired volume
- At the final testing teams will have 10 minutes to launch a maximum of 10 balloons
- Teams may make adjustments during this 10 minutes
- Balloon distance will be measured based on where it first impacts the ground
- Balloons which break during launch will be measured based on where the rubber first impacts the ground
- Any design which is damaged so badly it is deemed unsafe to launch, will receive a performance score of 0 for any remaining balloons

The performance scores for these projects were based on the distance from which the water balloon was launched and its accuracy on a target laid flat on the ground as shown in Figure 1.

The target had 3 scoring rings worth 1, 3, and 5 points. A launcher placed 50-69 ft. from the target received a distance score of 1 point while a launcher placed 115 ft. or further from the target received a distance score of 5 points. The total score for a balloon was determined as: target score x distance score. For example, a balloon launched from 70 ft. which landed in the 3 point ring earned a score of: 2 x 3 = 6 points. The total performance score for a team was calculated by summing up the score for each balloon in the final test. A team's overall performance score was determined as the sum of all balloons launched during the final testing and Table 2 was used to correlate the performance score to a performance grade. Figure 2 shows student-built projects for each of the three technologies.

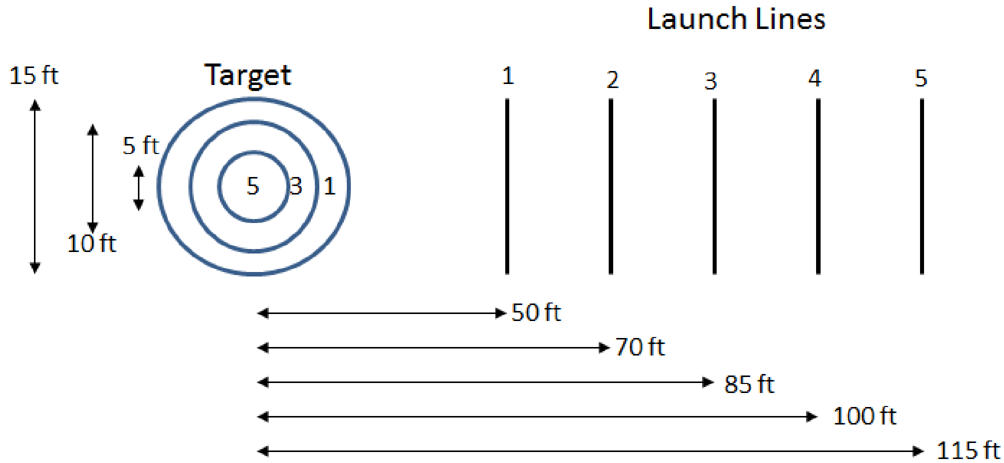

Figure 1. Water balloon launcher accuracy and distance criteria

a b c

Figure 2. Student built water balloon launchers - a) catapult, b) air cannon, c) trebuchet

Student Interest Rating Results

In the past two years 89 students have participated in the vehicle based design projects and 129 students have participated in the water balloon launcher projects. Each one of these students had the three projects described to them and was then asked to rate their interest on the Likert scale from 1-5 (1 = very disinterested, 5 = very interested) on each of the options. These ratings were used to split the class into small teams of 3-4 students and it is worth noting that it was possible to assign 98% of students to the project which they rated highest. The other 2% of students were assigned to the project they rated second highest.

The student interest ratings for the vehicle projects are shown in Figure 3 and summarized in Table 5. Of the three projects offered the students had a significantly higher interest in the car crash project as compared to the glider or potential energy vehicle project. If any one of those single projects would have been completed by the entire group of students, the average student interest rating for the project would have been 3.26-4.44 depending on the project. By allowing the students to rate their interest in the projects and then assigning them to teams based on these ratings the average interest in the project to which a student was assigned was increased to 4.61. In any one of the three projects the percent of students whose ratings were from very disinterested to neutrally interested (Likert = 1-3) ranged from 26-55% suggesting that if just a single project had been offered a large percentage of students would have been disinterested in the project. By allowing students a choice no student was given a project that they were disinterested in (Likert = 1-2) and only 4% of students participated in a project for which they were neither interested nor disinterested (Likert = 3). Thus, 96% of students were able to complete a project in which they had an interest.

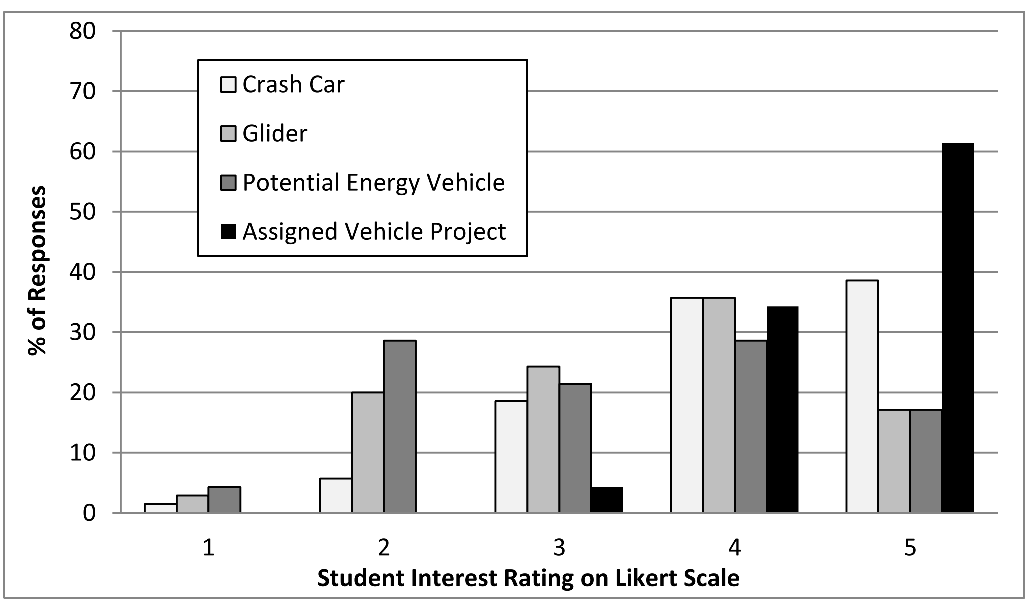

Figure 3. Student interest results for vehicle projects

Table 5. Summary of vehicle project interest ratings

	Average Rating	Standard Deviation of Ratings
Car Crash Project	4.4	0.96
Glider Project	3.44	1.08
Potential Energy Vehicle	3.26	1.17
All Projects	3.58	1.13
Assigned Project	4.61	0.58

The student interest rankings for the water balloon projects are shown in Figure 4 and summarized in Table 6. There was a similar level of interest in all three projects with the average student interest ranking varying from 3.56-3.84 depending on the project. The average interest rating for the project to which a student was assigned was substantially increased to 4.8. In any one of the three projects the percent of students whose interest ratings were from very disinterested to neutrally interested (Likert = 1-3) ranged from 33-41% while less than 1% of students were actually assigned to a project for this interest range. Thus, 99% of students were able to complete a project in which they had an interest because they were allowed to choose from the three options.

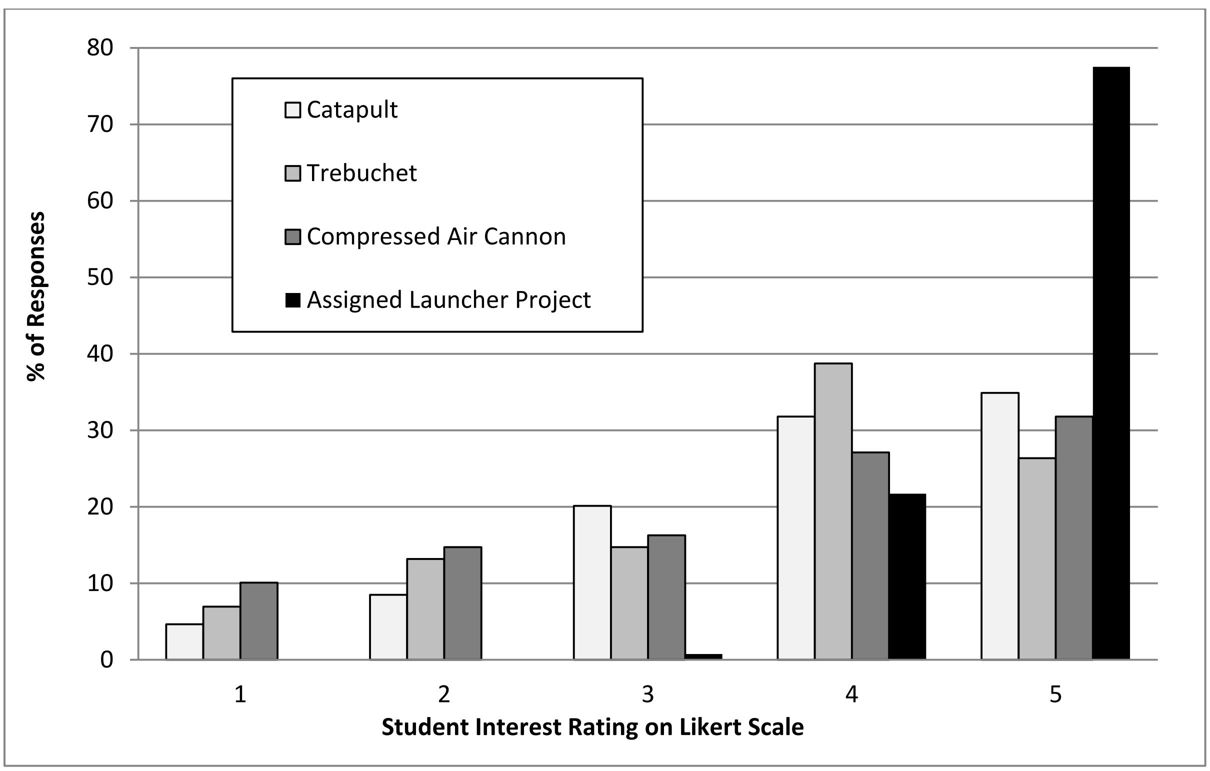

Figure 4. Student interest results for water balloon launcher projects

Table 6. Summary of water balloon project interest ratings

	Average Rating	Standard Deviation of Ratings
Catapult Project	3.84	1.14
Trebuchet Project	3.64	1.20
Compressed Air Cannon	3.56	1.34
All Projects	3.65	1.23
Assigned Project	4.80	0.41

These results show that both implementations were effective at tailoring to students interests which has been shown to promote a student's feeling of autonomy and motivation[6]. Due to the fact that this current study did not have a control group, and that the vast majority of students had a high interest level in their project, conclusions cannot be drawn directly based on student performance on a project and how it was affected by their interest and having a choice. However, greater interest in a task has been shown in the literature to correlate strongly with an increase in interest and enjoyment during the task and an increase in perceived competence and performance on the task[8].

Student Feedback

Following the projects a survey was administered to get feedback from the students to better understand their thoughts on studying topics which they find interesting. The quantitative results from this survey are shown in Table 7. It is seen that the students largely felt that the lab projects allowed them to learn more about something for which they had a pre-existing interest. According to Meadows, Fowler and Hildiner[7] this suggests that their interest and perception in engineering increased by participating in these DBT projects. A distinction is made here between a student being interested in participating in a given project, and a student being interested in the material content of a project. Consider for example that many students might want to participate in a project in which something explodes simply because it might be fun to blow stuff up rather than because a student is interested in learning more about explosions. This logic may explain the difference in student rating of interest in a project prior to completing it, and their agreement with the first statement in Table 7. It is also revealed that students do feel that their classroom material should overlap their interests, something which their other classes do not do to a significant degree.

Table 7. Survey questions and results

Statement rated from 1-5 (1=strongly disagree, 5= strongly agree)	Average Rating	Rating Standard Deviation
The lab projects allowed me to learn more about something I was already interested in or was looking forward to learning about	4.09	0.81
It is important that the material I learn in class/lab overlaps with my interests	4.34	0.85
My other courses/labs cover material which overlaps my interests	3.07	0.83

Students were also asked for input as to what interested them about the projects and a few key points can be summarized from their answers. Students commonly responded that they were interested in a project for some of the following reasons:

- Project seemed easier than others.
- Project seemed more challenging than others.
- I wanted to build on a previous experience with a similar project.
- I had already done a similar project and wanted to try something new.
- Have always been interested in that type of thing.
- Project seemed to allow for most creativity.
- "It just seemed cool."
- "Who doesn't want to crash a car into a thick metal plate?"

Based on the variety of responses and the clearly contradictory attitudes of the students as a population it would seem impossible for an instructor to develop a single project that can accommodate the widely varying motivations of students.

Conclusions

This paper demonstrates that by offering students three options for DBT projects the level of student interest in the project to which they are assigned increases significantly above what it would be if a single project were assigned. This was true when the three projects offered all had very different objectives, as well as when the three projects all had an identical objective. From an instructor standpoint this is important as the task of developing three separate projects and grading rubrics can be a lot of work, while developing a project that could be done three different ways is much simpler. This project further demonstrates the seemingly unavoidable futility in coming up with a single project that would appeal to all students. This conclusion is based upon the relatively large percent of students with no interest in a given project for all projects described as well as the wide variety of student motivations for being interested in a project. The relevance of student interest to student motivation and thus project performance is made from the standpoint of self-determination theory which suggests that giving students the ability to choose results in greater a feeling of personal autonomy. Finally, it is shown that students see a value in finding an overlap between their personal interests and the material they cover in class. By providing students with a choice on lab projects it was found that a course can be made to better cater to students interests than the average class they take in their first year(s) of college.

Plans are currently being made to expand upon the results described in this paper. Specifically, the goal of this future work will be to examine the effect of choice on student learning and project performance.

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