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The Effect of Project Constraints and Choice on First-Year Microcontroller Projects

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Abstract

Literature on self-determination theory suggests that giving students a choice can lead to many positive effects, however too much choice can actually be detrimental. This paper discusses the effect that the project constraint level has on student performance and perception during projects which require the use of microcontrollers. The projects were implemented in two different versions of a one credit introduction to engineering course that consists of both mechanical and electrical/computer engineering students at an urban, private institution in the Midwest (University of St. Thomas).

As part of their introduction to engineering course, students were given a choice between hands-on Arduino (a microcontroller) projects which differed in the amount of freedom students had over the components used and project objective. Multiple projects were offered which had a clearly defined objective and specified exactly which sensors and actuators to use in meeting those objectives. A more open-ended project was also offered in which students could choose their sensors and actuators and develop their own project objective.

Pre-project surveys were used to gage student interest level in the various projects, sensors and actuators as well as their experience with microcontrollers and programming. It was found that 93% of the students had not programmed microcontrollers before entering college. Students were assigned to the microcontroller project for which they rated the highest interest. A post project survey was used to assess the amount of time spent, perceived difficulty of the various projects, perceived learning and biggest challenges presented by each project. To examine how the amount of choice relates to student outcomes on a project the survey results and project grades of students who chose a clearly defined project are compared to those who developed their own project. This paper further discusses open-ended feedback relating to the microcontroller project implementation, as well as challenges and opportunities for improvement.

Introduction

Many first-year engineering students have a cloudy picture of what engineering is and what engineers do. Given the broad range of engineering disciplines (mechanical, electrical, etc.), industries and engineering job functions (test engineer, research engineer, etc.) giving an accurate and clear picture that encompasses all that any potential engineer might experience is simply not possible. One also gets the sense that first-year students are inclined to believe that hands-on projects are one of the most attractive experiences for exposing them to the skills and problems that engineers encounter. 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.

However, giving students a number of hands-on projects to choose from can be one way to satisfy a number of attractive goals. When given a choice on projects students will naturally gravitate towards projects in which they are most interested. Past research done with first-year mechanical and electrical engineering students has shown that when presented with three project options the average interest rating for a population of students could vary, based on the exact project, from 3.26-4.44 on the Likert scale (3 = neutrally interested, 4 = somewhat interested, 5 = very interested)[1]. By assigning those students to the project for which they had the most interest the average Likert score for the assigned project rose to 4.61 and 96% of the students completed a project in which they had an interest. Further, results from this study reveal that first-year engineering students feel strongly that the material they learn in a class or lab should overlap with their interests, though they did not rate their other courses as doing so. Meadows, Fowler and Hildiner[2] have shown that student interest and perception in engineering increased when students explore topics aligned with the incoming interests. Additionally, by having multiple projects being worked on simultaneously in the same class, students will ultimately talk with students working on other projects and even see other projects being developed and tested. Thus, even though they might not be working on that project, they can witness the process of their classmates and be exposed to additional hands-on skills and technical engineering content through observation. It is believed that this helps students develop a clearer picture of the broad discipline of engineering.

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[3] 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 discuss that providing choice can result in an increased: sense of personal control, motivation, interest in a task, liking of a task, effort, performance, learning and perceived competence.

Patall, Cooper and Wynn[4] 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 many positive impacts, research suggests that all choices do not elicit the same effect on people[3]. Providing too few options, too many options, or options for which the choices seem unimportant or irrelevant can have a detrimental effect. Patall, Cooper and Robinson[3] conclude that providing three to five options from which to choose is typically most optimal, 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. Regarding the detrimental effect of too much choice, Schwartz offers four confounding effects[5-7]:

- Regret and/or anticipated regret – with more choices it is easier to second guess your decision making it easier to regret your decision making you less satisfied with the choice
- Opportunity costs – making a decision requires you to forego the attractive opportunities provided by the other options
- Escalation of expectations – with more options you expect more from your chosen option
- Self-blame – because you made the choice, if you are unhappy with it you feel responsible for disappointing yourself

In his TED Talk[6], Schwartz summarizes his understanding of the research on choice by stating "There is no question that some choice is better than none, but it doesn't follow from that, that more choice is better than some choice. There is some magical amount. I don't know what it is."

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. The current study examines how offering a choice in Arduino-based microcontroller projects impacts first-year students in a one credit introduction to engineering course with mechanical and electrical/computer engineering students. In particular, this research compares students' experiences on projects which are defined by the instructor with projects where students choose to design their own project. The primary research question being studied is: Do students who participate in a design-your-own microcontroller project (i.e. project where a lot of choices are required) have a significantly different experience than students who participate in an instructor-defined microcontroller project? Two different implementations of the microcontroller projects are analyzed using surveys and project grades to assess student attitudes, learning and interest. In the first implementation all students participated in a microcontroller project and had the choice between three instructor-defined projects or designing their own project. In the second implementation students were given a choice between two mechanically-oriented projects that were instructor-defined, two instructor-defined microcontroller projects and a design-your-own microcontroller project.

Design of Study

The introduction to engineering course at the University of St. Thomas is a 14 week, one credit course typically taken in a student's first-year. The university offers undergraduate mechanical,

electrical and computer engineering degrees. Surveys on introduction to engineering students show that roughly 78% are interested in mechanical engineering, 13% in electrical/computer engineering and 9% are thinking of another engineering field or are unsure if engineering is right for them. In addition to a lead instructor, students in the class are also assisted by two student mentors who are undergraduate engineering students that have completed the introduction to engineering course.

Pre-project surveys were used to examine previous student experience with microcontrollers and identify interest in potential sensors and actuators to be used in projects. It was found that 93% of the students had not programmed microcontrollers before taking the course. Thus, the students were provided with instructional packets and in-class activities on introductory coding in Arduino before working on their projects. Students also provided their interest ratings on a 0-10 scale (0 = no interest, 10 = great interest) for a variety of sensors and actuators as shown in Table 1. The sensors and actuators were discussed in class prior to taking the survey. The information gathered from the student interest ratings was combined with instructor assessment of the level of difficulty in wiring and coding the various components in order to define projects with an appropriate scope for the time frame and student ability. It is noted that many of the components that students had the highest interest in were also the most complicated for wiring and coding (i.e. ultrasonic rangefinder, LCD display).

Table 1. Pre-project survey results for student interest in using various sensors and actuators

Sensor	**Avg. Interest Rating**	**Standard Deviation**
Photoresistor	6.04	2.6
Thermistor	5.31	2.65
Ultrasonic Rangefinder	6.95	2.84
Solar Panel	6.45	2.88
Potentiometer	5.26	2.33
Pushbutton	6.39	2.43
Actuator	**Avg. Interest Rating**	**Standard Deviation**
LED	6.59	2.29
Speaker	7.55	2.24
Servo Motor	7.19	2.53
Fan	5.89	2.59
LCD Display	7.21	2.65
Thermoelectric Heating Module	5.53	2.82

The course was recently redesigned which allowed for the impact of choice on microcontroller projects to be examined in two separate, though similar, ways which will be defined as Case 1 and Case 2. The impetus for the redesign was to try to give the course more appropriate workload and contact hours for a one credit class. All of the students who took the class in the 2013-2014 academic year were in Case 1, while all of the students taking the class in fall 2014

were in Case 2. Thus, students could not choose which version of the course they took as only a single version was offered at a time.

Case 1: In Case 1 the class had a single 100 minute lecture and 100 minute lab each week. During the semester, five consecutive lab periods were dedicated to instruction and orientation to the Arduino Uno Rev 3 hardware and programming. All students in the class were required to participate in the microcontroller project. Overall, 133 students participated in Case 1 in which students could choose from four different Arduino projects. Students were assigned to the project for which they rated the highest interest, and they could either complete the project on their own or with a single partner. The four project options were:

- Controlled Robot – build a robot and controller that used push buttons, servo motors, photoresistor, LEDs and ultrasonic rangefinder
- Digital Temperature Controller – build a device that can monitor and control temperature using a thermistor, pushbutton, speaker, LEDs, fan and incandescent light bulb (heater)
- Party Bot – build a robot that moves and plays music using push buttons, servo motors, LEDS, photoresistor, and a speaker
- Design Your Own Project – students determine the functionality and select appropriate sensors and actuators with assistance of instructor to ensure proper scope

Case 2: In Case 2 the class had a single 100 minute meeting each week. Some of the weeks were lecture while others were largely devoted as lab periods. During the last six classes of the semester, roughly 75 minutes of each period was dedicated to instruction and orientation to the Arduino Uno Rev 3 hardware and programming of the project. Thus, Case 2 represents a 10% decrease for in-class time dedicated to the project, though the students had an additional week to work on the project outside of class as compared to Case 1. The authors believe that the time allowed for the students to complete the projects was negligibly different between the two versions of the class. The biggest difference from Case 1 is that the students in this implementation had the option of doing a microcontroller project or a mechanically-oriented project. Overall, 157 students participated in Case 2. Students were assigned to the project for which they rated the highest interest. Students completing a microcontroller project could work on their own or with a partner. The project options for Case 2 were:

- Kayak Bike Trailer – design, build and test a trailer that can be used to transport a kayak behind a bicycle
- Air Cannon Projectile/Barrel – design, build and test a barrel and projectile to be launched from an air cannon with the goal of sticking to an aluminum sheet metal target
- Party Bot – build a robot that moves and plays music using push buttons, servo motors, LEDS, photoresistor, and a speaker
- Bicycle Power Meter – build a meter that indicates the amount of power from a bike-powered generator using resistors, toggle switch, photoresistor, LEDs, speaker and LCD screen

- Design Your Own Project – students determine the functionality and select appropriate sensors and actuators with assistance of instructor to ensure proper scope

With regard to Case 2, the mechanical projects (kayak bike trailer and air cannon projectile/barrel) are described here for completeness. For the purposes of the current study, only the Case 2 students who participated in a microcontroller project are considered in the analysis. The expectations for the microcontroller projects in Case 1 and Case 2 were equivalent. It is noted that of 157 students in Case 2, 36 chose to complete a microcontroller project. Considering these 36 students, 67% had expressed interest in mechanical engineering and 33% had an expressed interest in electrical engineering.

Each of the microcontroller projects had varying point levels which increased as students added components and extra credit was available for sophistication in the coding. The Controlled Robot, Digital Temperature Controller, Party Bot and Bicycle Power Meter project choices had the functionality and coding logic precisely defined by the instructor (i.e. if pushbutton is pressed and the room lights are on then …..). The design-your-own project represents an option which is only constrained to ensure proper scope for the time allowed and for cost reasons. Students were informed that they could use any of the sensors or actuators seen in Table 1 and that additional components would be purchased (i.e. free to the student) so long as cost and safety were considered. Thus, students could choose between a small number of defined projects, or a project in which the number of choices required of the student would be very high (what should it do, how should it do it, what components should it use, etc.).

Results & Discussion

For both Case 1 and Case 2 a comparison can be made to reveal how the amount of choice on a project affected the student experiences. To this end, all of the instructor-defined microcontroller projects will be identified as "constricted choice" and the design-your-own project will be identified as an "open choice" project. In Case 1 there were 122 students (91.7%) who completed a constricted choice project and nine students (6.7%) who completed an open choice project. For Case 2 there were 31 students (86.1%) who completed a constricted choice project compared to five students (13.9%) opting for the open choice project. The average of all student interest ratings in the constrained choice projects is 3.7/5 (on Likert scale) compared to 2.9/5 for the open choice project. These results suggest that students, on average, have a significant preference in having the instructor sharply define the project. It is interesting to note that the percent of students completing the open choice projects is similar to the percent of students with prior experience programming microcontrollers. As some of the surveys used were anonymous it is unclear if there is a correlation between prior experience and choosing an open choice project.

It is noted that the average interest ratings in all of the offered microcontroller projects (constricted and open choice) was 3.4/5. The average interest rating for the project to which a student was assigned was substantially increased to 4.75/5 for constrained choice and 5/5 for the

open choice projects. 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[4]. Greater interest in a task has also been shown 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].

A post-project survey of the students was used to gather quantitative and qualitative feedback. Table 2 shows the questions asked on the survey. By having students list their project, the results could be categorized based on whether a student completed a constrained choice or an open choice project.

Table 2. Post-project survey questions

Q1. In terms of difficulty, how did the project compare with your initial expectations?				
(1) much easier than expected	(2) easier than expected	(3) it matched my initial expectations	(4) more difficult than expected	(5) much more difficult than expected
Q2. In terms of learning, how did the project compare with your initial expectations?				
(1) I learned much more than expected	(2) I learned more than expected	(3) It matched my learning expectations	(4) I learned less than expected	(5) I learned much less than expected
Q3. How much time did you spend outside of class/lab on your project?				
Q4. Rate your overall experience on this project from 0-10 (0 = awful, 10 = fantastic)				
Q5. How many points did your project earn?				
Q6. What was your biggest challenge and how did you overcome it?				
Q7. If you could change on thing about this project what would it be?				

The quantitative results from the post-project survey are presented in Table 3. The table shows the average student response with response standard deviation in parentheses for questions 1-5 (Q1-Q5) shown in Table 2. A series of two-sample t-tests were run comparing the Case 1 results for the constricted and open choice projects. The differences in the two groups results were not statistically significant except for their responses to question 2 (P value = 0.04). Thus, the Case 1 results reveal that the amount of choice had minimal impact on the student experience, though the students who chose a more constricted project report that they learned somewhat more than expected. Interestingly, that conclusion was not supported by the Case 2 results. Two-sample t-tests comparing the constricted and open choice results in Case 2 do not show any statistically significant differences. However, the difference in time spent outside of class in Case 2 between

the groups is close to being statistically significant (P value = 0.058). The results between mechanical engineering students and electrical/computer engineering students were also analyzed using two-sample t-tests. The only statistically significant difference in experience found was that electrical/computer engineering students doing a constricted choice project spent on average two hours less in completing their projects than mechanical engineering students doing constricted choice projects. This was true for Case 1 and Case 2.

Table 3. Post-project survey results: average (standard deviation)

Case 1	**Q1 (difficulty)**	**Q2 (learning)**	**Q3 (time spent – hrs)**	**Q4 (overall experience)**	**Q5 (score)**
constricted choice	3.4 (1.0)	2.1 (0.8)	4.8 (2.3)	7.5 (2.3)	95.0 (11.7)
open choice	3.0 (0.6)	2.8 (0.4)	5 (3)	8.7 (2.3)	98.3 (6.7)
Case 2	**Q1 (difficulty)**	**Q2 (learning)**	**Q3 (time spent – hrs)**	**Q4 (overall experience)**	**Q5 (score)**
constricted choice	3.4 (0.8)	2 (0.7)	5.3 (1.9)	8.7 (1.8)	94.9 (13.0)
open choice	3.6 (0.5)	2.2 (0.8)	7.3 (1.5)	7.6 (2.6)	93.4 (9.7)

The open-ended questions from the post-project survey reveal a couple of interesting results regarding the impact of choice. In creating a taxonomy of the student feedback it was found that the biggest challenges students experienced were in coding, wiring and hardware related issues. The response rate for these was found to be roughly equivalent for students participating in the constricted projects (~ 25% response frequency each). However, on the open choice projects hardware issues were more frequently given (~ 50%) as the biggest challenge. This is largely due to the fact that for many of the open choice projects students acquired hardware that was not common to the lab (i.e. LED array, LED strip, DC motor, laser diodes). The instructors and student mentors had less experience with these components which made their troubleshooting a bit more challenging. The second interesting result comes from comparing the Case 1 and Case 2 feedback from students who completed the constricted projects. In Case 1, when 3 constricted project options were given, only 6% of the student feedback on how to improve the project involved adding more project options. In Case 2, when 2 constricted project options were given, 39% of the student feedback on how to improve the project related to adding more project options. From this it is concluded that offering 3 constricted project options is better than offering 2 for first-year student micro-controller projects.

An analysis of all of the project feedback reveals that there is a trend showing a correlation between overall student experience and project grade as shown in Fig.1. When similar regressions were run comparing the overall student experience rating with perceived difficulty, learning, or time spent on the project the correlations were poor and resulted in R^2 coefficients of 0.32, 0.32 and 0.42 respectively. These results suggest that efforts made by an instructor to help students achieve a strong grade on a microcontroller project may improve the student experience even if they result in a project taking more time or being more difficult.

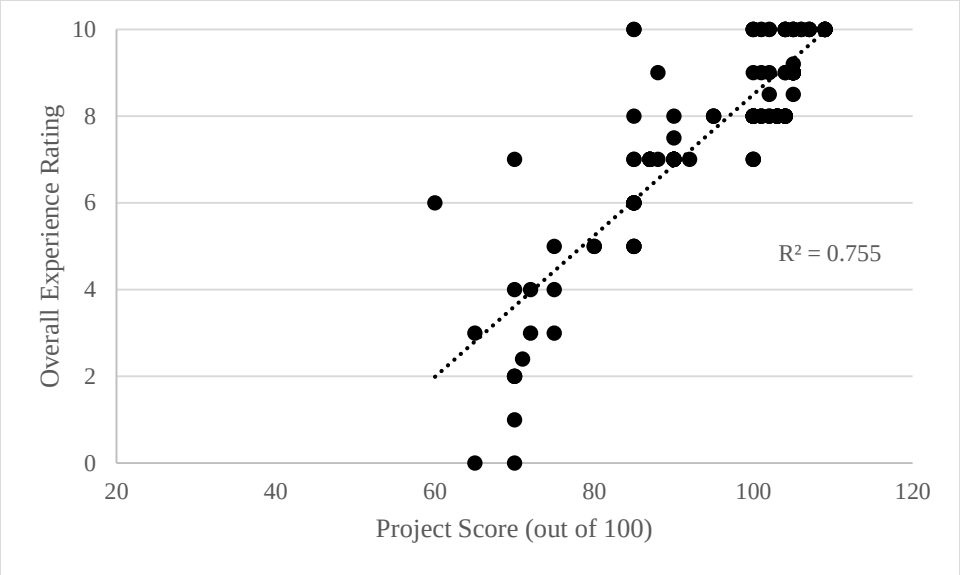

Figure 1. Comparison of overall student experience rating against final project score (for all projects in Case 1 and 2)

In comparing the Case 1 and Case 2 student ratings of their overall experience, regardless of project choice, one finds a statistically significant difference (P value = 0.018). In Case 1 all students in the class were required to complete a microcontroller project and the mean rating of the experience was 7.52. In Case 2 the mean microcontroller experience rating was 8.51 though these students had a higher interest in completing a microcontroller project than the mechanical engineering project options (i.e. they choose to complete a microcontroller project). This suggests that students who have a higher initial interest in a project will ultimately have a better overall experience, a result that is in agreement with the literature on self-determination theory[2-4,8].

Instructors of first-year engineering classes that include students interested in multiple engineering backgrounds therefore have an interesting choice to make. A case can be made for the importance of providing a broad exposure to engineering by requiring students to participate in projects outside their areas of interest. One could argue that because most first-year students do not have a clear picture of engineering, that exposing them to various disciplines will help them determine which discipline to pursue. One might also argue that even if a student knows which engineering discipline they want to pursue, exposure to additional fields of engineering is useful for approaching multi-disciplinary problems. However the results suggest that doing so might be perceived as a less positive experience than allowing the students a choice in the content and projects to which they are engaged.

Conclusions

This paper examined the impact of allowing students to design their own microcontroller as compared to students choosing an instructor-defined microcontroller project. These two scenarios were considered to represent an option in which a student would have to make a lot of choices and an option where the student would only need to select a project from a small number

of options. Past research in psychology, and specifically self-determination theory, suggest that presenting a student with some choice can have a positive effect though presenting a student with too much choice can have a detrimental effect. The authors want to make clear that there exists a distinction between a student choosing to design their own project (which requires a lot of choices to be made) and presenting a student with a lot of project choices. The student who opts for designing their own project is deciding to take on all of the requisite decisions that come with such a project. This student could feel even greater autonomy which is positive, though the impact of having to make so many decisions (and live with them) also has the potential to be deleterious. The results from post-project surveys show that students who choose the option of designing their own microcontroller project as opposed to choosing a more constricted project option do not have a significantly different project experience as compared to the students who chose a constricted project. The data collected suggests that design-your-own microcontroller projects can take more time than instructor defined projects, though the student expectations of learning and difficulty as well as their rated experience on the project and project grade are similar. It was found that only a small fraction of first-year engineering students preferred to design their own project with the majority choosing to participate in an instructor-defined project. It is possible that the students who would be more easily overwhelmed by an increased level of decision making self-selected the more constricted projects. By offering multiple options, and a design your own project option it was found that student interest and overall experience with their projects was much higher than if a single project had been offered.

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