Toward Understanding the Impacts, Whys, and Whats Behind Mechatronic-based Projects and Student Motivation

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Abstract

The purpose of this study was to understand the how's, why's, and what's behind students' motivational orientation in a first-year engineering technology course, following a mechatronic project. To accomplish this, we implemented an eight-week treatment that required 61 students to design and integrate a software program to control an electro-mechanical robotic system. Using non-parametric quantitative analyses of pre-/post- survey responses we found that students' median motivational orientation score, on the Motivated Strategies for Learning Questionnaire, was significantly lower ($Mdn_{diff} = -0.34$; $W = 1360$; $p\text{-value} = 0.0111$) following the mechatronic project (i.e., they were less motivated to engage in the learning process following the project). However, when asked directly, a significantly larger proportion of students reported that it was motivating ($\rho = 0.90$; $p\text{-value} < 0.010$). To clarify these divergent results, we used a mix of text-mining algorithms and word stem frequency analyses to examine open-ended student responses. From this we discovered the word stems *work*, project*, learn*, program*, want*, see*, motiv**, and *robot** to be the most prevalent used for "why" the mechatronic project was motivating; the word stems *work**, *code**, *get**, *motiv**, *robot**, *see**, *project**, *want**, and *complet** were the most commonly reported for "what" motivated students. From this we start to uncover the "why's" and "what's" behind students' motivation: namely, that the visual and physical aspects of the mechatronic project were motivating to them.

Keywords: student motivation; engineering education; mechatronics

1. Introduction

Meece defines student motivation as the "desire to work and learn" [1, p. 5]. While this operational definition is concise, it may not have been intended to fully describe the complexity of factors that affect student motivation. In Clark's [2] work on goal commitment and effort, he cites two complementary definitions: 1) motivation is "…the process whereby goal-directed activity is instigated and sustained" [3, p. 4]; and 2) "…the amount and quality of the 'mental effort' people invest in achieving goals" [2, p. 2], which was borrowed from the work of Bandura [4] and Salomon [5]. Furthermore, Pintrich, Marx, and Boyle [6] indicated value choices, expectancy beliefs, and meta-cognition as three major factors of student motivation. In their motivation-cognition model, value choices are comprised of *goal orientation*, *interest*, and *importance*; expectancy beliefs are comprised of *self-efficacy*, *attributions*, and *control beliefs*; and meta-cognition is comprised of *self-regulated learning*. Here, motivation is viewed as the "energy" that drives one's self-regulation toward learning. This motivation-cognition model takes the perspective that meta-cognition and motivation form a symbiotic and dynamic relationship. A person continually evaluates intrinsic and extrinsic feedback to dynamically adjust their motivation towards learning [7]. We took this perspective of student motivation in our study.

Many theories and perspectives have been developed on how to impact students' motivation. Linnebrinck-Garcia [8] indicated that the structure of the classroom is a tangible environment in which to affect change, while Meece [1, p. 2] states that, "…schools and teachers can encourage or discourage…learning through the ways in which they structure the learning environment." Furthermore, student motivation is "sensitive to context" and "…schools can make changes in the learning environment that increase the number of students who stay engaged and motivated…" [1, p. 7] Pintrich *et al*. [6] also support this notion, as they indicate that real-world projects and activities in the classroom have the potential to motivate students to engage with learning. Taking this a step further, many have pointed to mechatronic projects (e.g., design projects that integrate mechanical, electrical, and computer systems) as real-world, hands-on activities that can positively affect students' motivation to learn technical content. A recent systematic review of literature examining the influence of mechatronic projects on student engagement found positive impacts on student motivation [9]. However, gaps were highlighted by this review relative to the rigor of research designs (i.e., limited control vs. treatment or pre- vs. post-test usage), clarity of methods (limited explanation of experimental methods), and depth of analysis (i.e., discerning the defining qualities of the research). In short, evidence supports the motivational value of mechatronic projects, but stronger and more detailed evidence is needed to more firmly establish this premise. Therefore, the first goal of our research was to empirically quantify the impact that a mechatronic project can have on students' motivational orientation. Secondly, we sought to understand the why's and what's behind this motivational impact. Specifically, we asked the following questions.

1. How is student motivation impacted by a mechatronic project?
2. Why is a mechatronic project motivating to students?
3. What aspects of a mechatronic project are motivating to students?

2. Materials and Methods

2.1. Mechatronic Project

The hardware and software used in our mechatronic project was an Arduino UNO microcontroller (Arduino, USA), ZUMO v1.2 robot (Pololu, Las Vegas, NV), and the Arduino 1.6.10 Integrated Development Environment (Arduino, USA). Students were required to integrate the mechanical and electrical hardware of the robot with original software programs to autonomously navigate through a predefined maze. In the first four weeks of the project, they were individually responsible for completing five topic-centric activities (Table 1), which focused on software (program code) and hardware (motor and sensor) integration skills. With this foundation, they were given the last four weeks to develop, test, and implement their designs on the robot. The administration of this project was significantly informed by the methods and lessons learned from others. [10]–[16]

Table 1. Detailed schedule of the mechatronic project and associated activities.

Week	Week Topic	Project Requirements
8	Introduction, IDE, Structure Variables, Data Types	Complete five Mechatronic Activities
9	Arithmetic, Constants Flow Control, Switch Case, Break	
10	Digital & Analog I/O, Time	
11	Motor & Sensor Functions	
12	Challenge Task Development	Complete one of the Mechatronic Project challenge tasks in teams of four students 1. Manufacturing Part Delivery Task 2. Agricultural Harvesting Task 3. Animal Science Health Monitoring Task
13	Challenge Task Development & Testing	
14	Challenge Task Testing	
15	Challenge Task Completion/Presentation	

2.2. Survey Sample Population

The theoretical population for our study were undergraduate students enrolled in fundamental engineering, engineering technology, technology, or applied engineering courses. Within this population, we focused on a convenience sample of undergraduate students enrolled in a first-year course in technology (i.e., Solving Technology Problems) offered by the Department of Agricultural and Biosystems Engineering at Iowa State University, Ames IA. The term "fundamental course" was defined as a first-year class that occupied the core requirements of the department's Industrial Technology and Agricultural Systems Technology majors. We sampled 61 students from two sections of this course. Eighty-four percent were pursuing degrees within our department, while the remaining 16% were pursuing a range of degrees in agricultural business, agricultural exploration, agricultural studies, agronomy, and food or animal science. Gender splits were 92% males to 8% females, while the ethnicity split was of 91% non-underrepresented (i.e., White/Caucasian) students to 11% underrepresented students. Students 18 – 19 years old comprised 82%, students 20 – 23 years old comprised 15%, and students over 23 years old comprised the remaining 3%.

2.3. Survey Instrument
We measured students' motivational orientation using a pre- vs. post-test survey design. The instrument used was Pintrich and colleague's [17] *Motivated Strategies for Learning Questionnaire (MSLQ)*, which originated from the work of the National Center for Research to Improve Post-Secondary Teaching and Learning. This instrument takes a meta-cognitive perspective of student motivation and learning. Specifically, it is predicated on the motivational constructs of *value*, *expectancy*, and *self-regulation*. As endorsed by the MSLQ manual [17], we used only a subset of the motivation scale items to measure students' motivational orientation. Specifically, we used 26 of the 81 total questions available on the MSLQ (Table 2). Responses for each question were ordinal Likert Scale data, ranging from 1 ("*not at all true of me"*) to 7 ("*very true of me"*).

In concert with the motivation scale items on our post-test survey, we included a multinomial response question that ask whether students were motivated by the mechatronic project. As part of this question, students were first presented with Meece, Pintrich and Schunk, and Clark's defenitions of motivation (see Introduciton) and then asked "Was the final project motivating to you? Yes, No, or Neither". For students who answered "Yes", we then asked them, via open-ended text responses, "why" and "what" was motivating about the mechatronic project.

Table 2. MSLQ sub-scale item questions used to measure students' motivational orientation.

Sub-scale Items	Questions[1]
Value Components	
Intrinsic Goal Orientation (IGO)	1, 16, 22, 24
Extrinsic Goal Orientation (EGO)	7, 11, 13, 30
Task Value (TV)	4, 10, 17, 23, 26, 27
Expectancy Components	
Control of Learning Beliefs (CLB)	2, 9, 18, 25
Self-Efficacy for Learning and Performance (SE)	5, 6, 12, 15, 20, 21, 29, 31

[1]There are 31 questions within the motivation scale of the MSLQ.

2.4. Data Collection
We collected pre- and post-test surveys during the spring 2016 semester. The pre- and post-test surveys were both administered through Qualtrics (Provo, UT), with the pre-test collection occurring during week eight of the semester, and the post-test collection occurring during week 16. This pre- vs. post-test design allowed us to measure changes in students' motivation orientation relative to the mechatronic project. Incentives, capped at 1% of the students' course grade, were awarded to participants who complete both a pre- and post-test surveys. The pre-test responses were linked to post-test responses via the unique last five digits of students' identification numbers. Once this data link was made, and before the results were analyzed, all identifying information was removed from our data set. Additionally, all students received an informed consent allowing them to "agree" or "not agree" to participate in the MSLQ surveys. No students under 18 years of age, or who did "not agree" to participate, were included in the dataset.

2.5. Data Analysis
We performed quantitative analyses using RStudio (RStudio, Inc., Boston, MA) and R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria) with Type I error rates set at $\alpha = 0.05$. To answer the question of how students' motivational orientation was impacted following a

mechatronic experience, we analyzed differences in pre- vs. post-test survey results of the MSLQ items using a Wilcoxon rank-sum test. The use of this non-parametric method was dictated by the non-normality of our ordinal response data, as supported by an Anderson-Darling test statistic of $A = 1.22$ and a $p\text{-}value = 0.00329$ (Table 3). [18] Next, using a Binomial Exact test, we analyzed the difference in the proportion of students who reported "Yes" vs. those who reported "No" or "Neither" to the question of whether the mechatronic project was motivating. These two tests (i.e., Wilcoxon rank-sum test of median differences and Binomial Exact test of proportional differences) were used to determine whether students' motivational orientation was significantly impacted (i.e., $p\text{-}value < 0.05$) following the mechatronic experience.

To answer the questions of why and what was motivating to students about the mechatronic experience, we used a mixed method approach of text mining algorithms, word counts, word clouds, thematic content analyses, and unstructured conversations with students. Specifically, we used Java Gui for R's [19] and DeducerText [20] packages to transform students' open-ended text responses to the questions of "why" and "what" was motivating about the mechatronic experience. This transformation included algorithms that converted all response terms to lower case as well as removed all punctuation marks, numbers, "stopwords", and white space. We then combined all terms with similar word stems (e.g., programming and program were combined) to form a common language across all responses. This aligns with methods commonly used in qualitative and systematic review studies, which form a common language across multiple primary data sources [21]. After we transformed the text data, we then examined the frequencies of each term to infer common themes across the students' responses. We then used frequency charts, word clouds, and unstructured conversations with each student to synthesize meaning behind "why" and "what" was motivating about the mechatronic project.

3. Results and Discussion

3.1. Impacts

Our analysis of pre- vs. post-tests showed that students' motivational orientation scores decreased. Specifically, we found students' mean scores on the MSLQ survey dropped by 0.37 points ($M_{diff} = -0.37$; $se = 0.080$) following the mechatronic project (Table 3). However, we were mainly interested in whether this change was significantly different from 0.00 (i.e., did students' motivational orientation significantly change following the mechatronic project?). While many have indicated this to be the case, none, to our knowledge, have performed statistical tests to answer this question. Because our response variable was non-normally distributed, we used a non-parametric Wilcoxon rank sum test ($n = 61$) and found that students' median motivational orientation score was significantly different ($Mdn_{diff} = -0.34$; $W = 1360$; $p\text{-}value = 0.0111$), lower, following a mechatronic project (Table 3). Specifically, we were 95% confident that the true difference in pre- vs. post- median scores was between -0.60 and -0.090. This would indicate that students' median motivational orientation following a mechatronic project was negatively impacted. However, we additionally looked at the proportion of students who reported the mechatronic project to be motivating compared to those who did not. Using a binomial exact test ($n = 61$) we found a significantly higher proportion of students reported the mechatronic project was motivating ($\rho = 0.90$; $p\text{-}value < 0.010$). Moreover, we were 95% confident that the true probability of students reporting the mechatronic project to be motivating was between 0.82 and 1.0. This indicated that a high proportion of students felt the project motivated them. While this result is in stark contrast to those from the MSLQ survey, is it interesting to note that research has found that students' motivation waxes and wanes over the life-cycle of a project. [22] Even though post-project levels were lower than pre-project levels, this does not mean that it was not motivating to students.

Table 3. Results to MSLQ items and multinomial question.

Ordinal Responses to Value & Expectancy MSLQ Items (pre- vs. post-test)		Multinomial Responses to "Was the final project motivating…" (post-test)		
Descriptive		Descriptive	Frequency	Count
n	61	n		61
M_{diff}	-0.37	yes	0.90	55
sd	0.64	no	0.030	2
min	-2.4	neither	0.070	4
max	0.75			
se	0.080			
Anderson-Darling test				
statistic (A)	1.22			
p-value	0.00329			
Wilcoxon rank-sum test		Binomial exact test		
statistic (W)	1360	ρ	0.90	
p-value	0.0111	p-value	< 0.010	
Mdn_{diff}	-0.34	95% CI	0.82 1.0	
95% CI	-0.090 -0.60			

3.2. Why's and What's

If we assume that the mechatronic project was in fact motivating (base on the previous section's *$\rho = 0.90$; p-value < 0.010*), the next question is "why was it motivating?". To answer this, we analyzed students' open-ended responses and found the word stems *work**, *project**, *learn**, *program**, *want**, *see**, *motiv**, and *robot** were the most frequently used (Figure 1). We interpreted these terms to indicate common themes being communicated as to "why" the project was motivating. While the meaning of the themes of *learn** and *want** were unclear, we interpreted the other terms to indicate that students felt that *see*[ing] their *program** and *robot** *work** was why the mechatronic *project** was *motiv*[ating]. This explanation, which triangulated term frequencies and student conversations, appears to highlight the visual and physical aspects of the mechatronic project. This conclusion is corroborated by others, who have pointed to the tangible nature of mechatronic projects and their ability to motivate students [13]. The visual and physical feedback students experience after completing the mechatronic project appears to be the driving force for "why" they were motivated.

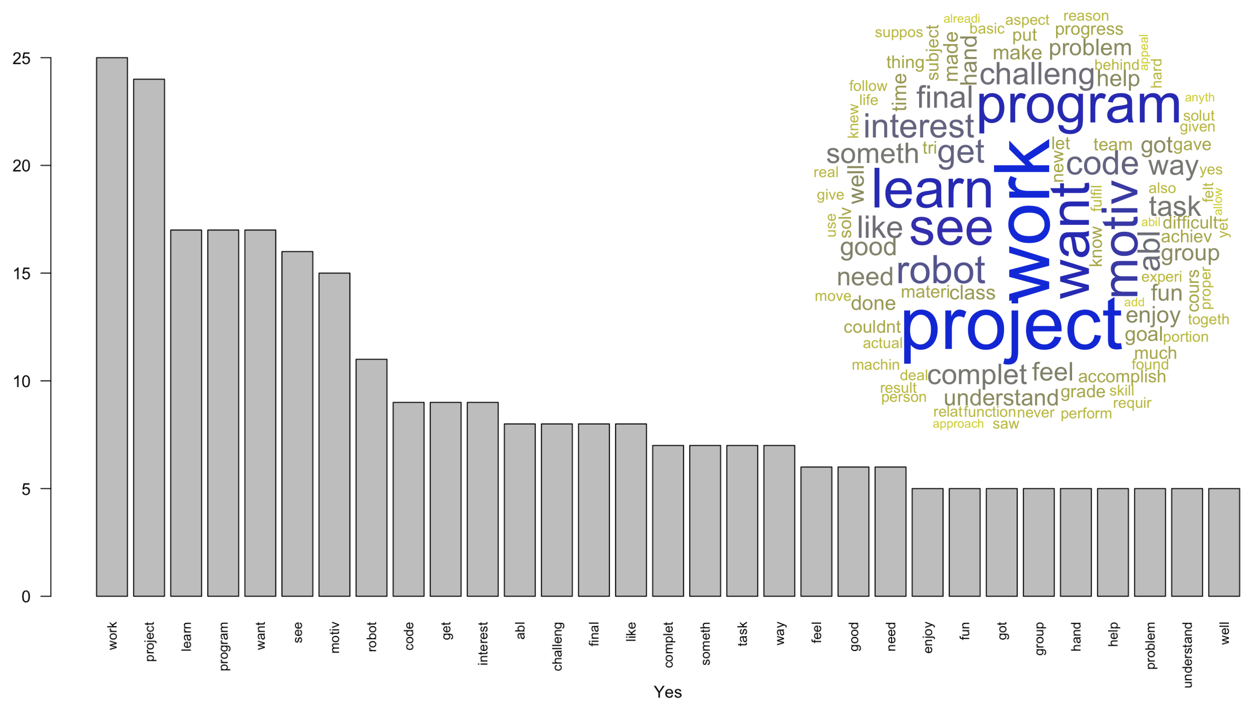

Figure 1. Frequencies and word cloud of word stems used by students when indicating why the mechatronic project was motivating (bar chart illustrates only terms with frequencies ≥ 5).

To answer “what” aspects of the mechatronic project were motivating to students, we examined students’ open-ended responses and found the word stems *work**, *code**, *get**, *motiv**, *robot**, *see**, *project**, *want**, and *complet** to be the most frequently cited (Figure 2). Interestingly, two-thirds of these terms (i.e., *work**, *motiv**, *robot**, *see**, *project**, and *want**) were also most commonly cited in students’ responses to “why” the mechatronic project was motivating. This highlights two key findings. First, we interpreted the common terms to indicate that students were motivated by *see*[ing] or *get*[ting] the *robot** and *code** to *work**; that these aspects of *complet*[ing] the project were what motivated them. The visual, physical feedback from the project was what was associated with their positive motivational orientations. Second, students appeared to form a common lexicon when describing the why’s and what’s of their motivational orientation relative to the mechatronics project. This points to a deeper meaning behind “why” the project was motivating and “what” aspects about the project impacted students’ motivation. Specifically, the tangible feedback experienced from the mechatronic project was associated with “why” and “what” was motivating to the students. While not necessarily unique to mechatronic projects alone, these tangible experiences are a hallmark of project-based learning, which has been found to motivate students [23], [24].

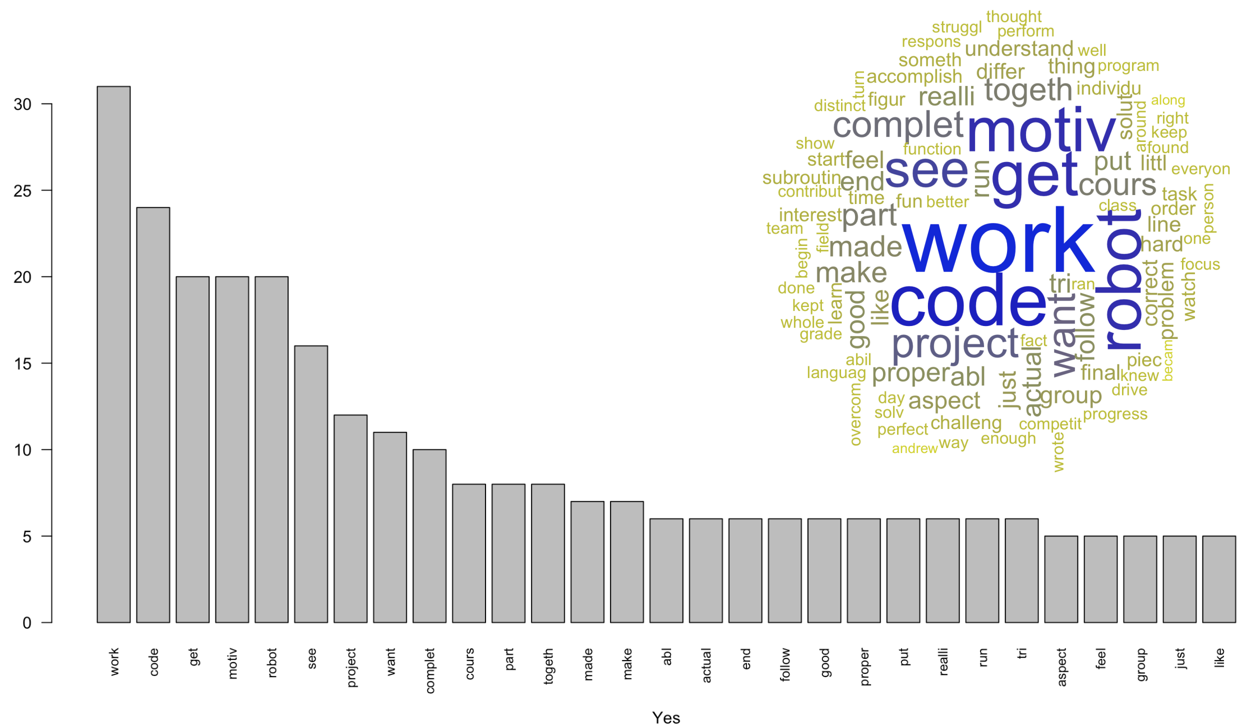

Figure 2. Frequencies and word cloud of word stems used by students when indicating What aspect(s) of the mechatronic project were motivating (bar chart illustrates only terms with frequencies ≥ 5).

3.2. Limitations

The results from our Wilcoxon rank-sum and our Binomial Exact tests are contradictory: the median difference results suggest that our treatment had a negative impact on students' motivational orientation, while the proportional results indicate the treatment was a wild success. These findings appear to illustrate the difference in results that a multi-question Likert Scale instrument can have compared to a single item question. And herein lies a driving force behind our research. Much of the current literature has implied positive outcomes to student motivation following a mechatronic project. However, the research designs undergirding these findings appear to have been predicated on single item questionnaires administered once. If the impacts – pro and con – of these experiences are to be more fully understood, multi-item instruments in conjunction with pre- vs. post-tests and control vs. treatment group designs are needed. Therefore, we feel it is very important to compare the results of this paper to a control group. This will allow us to remove confounding variation due to pre-/post-test timing (e.g., does students' motivational orientation decrease at the end of the semester regardless of treatment type?). For now, we temper our negative MSLQ results with research findings [22] that show students' interest (a construct of motivation [6]) wains towards the end of a project. However, even without this control group comparison, we feel we have begun to provide an empirical evidence base for understanding the impacts that mechatronic projects can have on student motivational orientation. We also feel we have explicated some of the why's and what's behind this motivation. Most notably, our findings indicate that these students were positively impacted by the visual and physical elements of our treatment. This alone is interesting, albeit we are unsure whether this is a genuine result from our treatment. It could simply be an artifact of project-based treatments in general.

4. Conclusion

In this paper, we presented the results of the impact that a mechatronic project had on students' motivational orientation, why they were motivated, and what aspects of the project motivated them. Our treatment was conducted in a first-year, fundamental engineering technology undergraduate course at a large, mid-western land grant university. While we found the median difference in students' motivational orientation decreased pre- vs. post-test, we also found that an overwhelming proportion of students indicated that the project was motivating. Furthermore, from our qualitative analysis of students' open-ended responses to "why" and "what", we found common word stems were used across the entire 61 student sampling frame. This would indicate that students formed a common language with which they explained why and what was motivating about the project, specifically the visual and physical elements of the project.

4.1. Acknowledgements

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