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Engineering Design Activity: Understanding How Different Design Activities Influence Students' Motivation in Grades 9-12

Final Report

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Abstract

The objective of this study was to evaluate grade 9-12 students' motivation while engaged in two different engineering design projects: marble-sorter and bridge designs. The motivation components measured in this study were focused on students' intrinsic (IGO) and extrinsic (EGO) goal orientations, task value (TV), self-efficacy for learning and performance (SELP), and control belief (CB). After finishing each project, students were asked to complete an Engineering Design Questionnaire (EDQ) survey instrument. The instrument consisted of 26 items modified from motivational scales of the Motivated Strategies for Learning Questionnaire (MSLQ).Besides the motivational scales, five demographic and two open-ended questions exploring students' most and least motivating aspects about their designs were added to the instrument.

From the statistical tests, the results showed a significant difference on students' IGO during marble-sorter and bridge design activities. Students' intrinsic goal orientation was significantly higher on bridge design than marble-sorter design. Students who planned to major in engineering or technology education were more significantly motivated working on the two design activities than those who whose majors were in other areas. Students' EGO did not appear to be correlated to their IGO, TV, SELP, and CB. Common themes associated with student motivation in the activities are presented in this report.

Introduction

There is a shortage of engineering students in many engineering colleges and universities. Scholars and educators argue that one of the reasons for the limited number of students interested in engineering education is because of their lack of sufficient science and mathematics skills. Various efforts, such as inviting students to participate in engineering design competitions and advocating students to enter engineering school have been attempted to attract high school students to enroll; however, these efforts have been less than successful. In the educational research domain, few studies have been conducted to investigate the issue from the perspective of the students' perception about engineering activities. Is the lack of science and mathematics skills the main reason for the shortage, or are there other factors, such as insufficient analytic skills that demotivate students to engage in engineering design activities? Although there may be numerous factors that contribute to the shortage of engineering students, evaluating student motivation in relation to different design activities should positively contribute to the knowledge building in the field of engineering and technology education particularly at the precollege level. This study was to evaluate how approaches to solve a design problem affect students' motivation in grades 9-12.

To solve an engineering design challenge, grade 9-12 students were encouraged to apply a standard set of steps to systematically lead to a solution. As educators, it may seem logical to assume that these rigorous engineering problem-solving steps may influence how the students perceive the design process and what engineering is all about. The students' perception of their engineering design activities impacts their motivation to learn about engineering and pursue the curriculum as their field of study in college.

Inasmuch as the intent of this study is to better understand how different approaches to solving an engineering design problem impact students' motivation, two distinct design projects were chosen: a design challenge that relies on design analysis (i.e., bridge design) and one that relies on a creative trial-and-error process (i.e., marble sorter). Approximately 80 students in grades 9-12 from several schools that implemented the Project Lead the Way (PLTW) curriculum participated in the study. Two versions of the Engineering Design Questionnaires (EDQ) were used to assess students' motivation: EDQ-Bridge-Design (EDQ-BD) and EDQ-Marble-Sorter-Design (EDQ-MSD). One research question was constructed to guide the study: How do analysis-focused and creative trial-and-error-focused design activities impact students' motivation?

Purpose of the Study

The purpose of this study was to better understand how different approaches to solving an engineering design problem impact students' motivation. This study evaluated students' motivation while working on two distinct engineering design activities: a design challenge that relies on design analysis and one that relies on a creative trial-and-error process. The design analysis is analogous to the engineering design procedure and the creative trial-and-error approach is associated with a technological problem solving approach.

Relevant Literatures

Engineering challenges that deal with both the design and construction of devices that satisfy constraints are increasingly used in K-12 science courses (Sadler et al., 2000). These engineering design projects engage students in "open-ended, science-based problem-solving situations" (Samuel, 1986, p. 218). According to engineering and technology education literature, K-12 instructors and college faculty involved in these relevant fields have reported high levels of student enthusiasm for these competitions. Sadler et al. (2000) further argued that many high school physics teachers have experimented with engineering challenges in their classes. These efforts generally use various construction materials to implement the time-constrained building of a working device designed to solve some imagined problem and "allow only a single competitive test after weeks of building" (Sadler et al., 2000, p. 300). Engineering design projects used in these courses are usually complex and time-consuming. The challenges emphasize design and communication solutions to complex problems and seldom optimize the utilization of the fundamental scientific principles (Sadler et al., 2000). Few studies have examined how different problem-solving approaches in engineering design influence high school students' motivation.

Motivation is a drive that stimulates students to achieve their objectives (e.g., academic success). Motivation can be embodied by goal-oriented behavior and reflects "the willingness of the students to exert high levels of effort toward achieving goals" (Chowdhury & Shahabuddin, 2007, p. 1). Motivation has an effect on how and why people learn as well as their performance (Pintrich & Schunk, 1996). It consists of several aspects: intrinsic motivation, extrinsic motivation, and self-efficacy, all of which have been widely discussed insofar as their interrelationship and effects on academic performance. While intrinsic motivation is defined as the student's inner inclination to engage in tasks for reasons such as challenge, curiosity, and mastery, the extrinsic reward (a source of extrinsic motivation) is one external incentive to the performance (Chowdhury & Shahabuddin, 2007). Self-efficacy refers to judgments about one's abilities to succeed in a given task (Bandura, 1997). In addition, it refers to beliefs in one's skills to "mobilize the motivation, cognitive resources, and courses of action needed to meet given situational demands" (Wood & Bandura, 1989, p. 408). Self-efficacy applies to a variety of contexts and is a good predictor of performance and behavior (Bandura, 1978, Gist & Mitchell, 1992). Numerous studies (e.g., Bandura & Schunk, 1981; Brown & Inouyne, 1978; Schunk, 1981; Weinberg, Gould, & Jackson, 1979) have suggested that strong self-efficacy beliefs are more likely to stimulate people to exert greater efforts to overcome a challenge, while weak self-efficacy beliefs tend to reduce people's efforts or even enable them to quit (Chowdhury & Shahabuddin, 2007). Self-efficacy beliefs influence people's behavior and motivation in several ways: they determine the difficulties of the goals people set for themselves; how much effort they exert; how persistent they are when confronted with difficulties; and their resilience to failures (Chowdhury & Shahabuddin, 2007). Task value refers to the students' perception of whether the task is interesting, important, and useful. Control of learning involves students' beliefs that learning depends on their endeavors rather than external causes, such as the teacher. In this sense, if students believe that their efforts towards achieving satisfactory outcomes have a positive influence on their learning, they will be more likely to engage in learning activities strategically and effectively.

Among numerous studies on motivation, there is a long-standing controversy over whether extrinsic rewards undermine intrinsic motivation. The central source of the contemporary debate is Deci, Koestner, and Ryan's (1999a) widely held claim that "tangible rewards tend to have a substantially negative effect on intrinsic motivation" (pp. 658-659). A number of scholars, including Eisenberger, Pierce, and Cameron, have offered contradictory statements and evidence to argue against the perspective of Deci et al. For example, Eisenberger et al. proposed the notion that the effects of extrinsic and intrinsic rewards are not interactive, but generally additive (Mawhinney, 1990; Porter & Lawler, 1968; Staw, 1977). Mawhinney (1979) argued that "We have not found support for the Deci-type theory. To the contrary, we have found evidence indicating that those people who are most highly intrinsically motivated by a task are those least likely to exhibit any post extrinsic reinforcement decrement to intrinsic motivation" (Mawhinney, Dickinson, & Taylor, 1989; Mawhinney, 1979; pp.188-189). Nevertheless, few studies have focus on the comparison of students' motivation, including intrinsic and extrinsic motivation, during two different engineering design activities that require two distinct problem-solving strategies.

Project Lead the Way

Project Lead the Way (PLTW) is a national nonprofit educational organization that provides middle and high school students with hands-on, rigorous, and preliminary courses involved in engineering or biomedical sciences. It creates partnerships with public schools, higher education institutions, and the private sector to prepare students for a successful career in the field of science, engineering, and engineering technology.

Historically, PLTW was launched in 1996 and first introduced to 12 New York State high schools in the 1997-1998 school year. Based on generous grants and hard work, PLTW was established as an independent nonprofit program by 1997. With the advent of its second decade, PLTW continues to grow and develop while continuing to provide rigorous and challenging courses. So far, the program has spread to 3,000 schools in 50 states as well as the District of Columbia.

Project Lead the Way (PLTW) curriculum activities were chosen for this study for two reasons. The primary reason was in the PLTW course, Principle of Engineering (POE), there are two hands-on problem solving activities that utilize two different problem-solving techniques, both common in engineering. The second reason is PLTW requires formal training of all of its teachers insuring more consistency in the delivery of the curriculum.

Principle of Engineering

The purpose of Principles of Engineering (POE), one of the courses in the high school program, is to explore technology systems and manufacturing processes, and address the social and political consequences of technological change through a combination of activities-, project-, and problem-based learning. It acquaints students with a wide range of careers in engineering and technology. The two activities selected from the POE course were the marble-sorter activity and the bridge design activity.

Marble-Sorter and Bridge Design Activities

The intent of the marble-sorter project is to design and build a device that sorts three different colors (blue, transparent, and opaque) of marbles into their respective bins. The marble-sorting activity requires a problem solving approach which requires creative thinking and testing for positive or negative feedback. Students design, assemble, program, and test multiple systems and subsystems before settling on a final solution. Prior to designing and building their marble sorters, students study data acquisition and control and programming techniques, and the assembly of Fischertechnik components. The Fischertechnik kits are the sources of all components except the hopper and the bin-moving systems.

The marble sorter consists of several functional systems, including the hopper, separation, sensing, trap door, and bin-moving systems, all of which work together through a computer interface to accomplish the objective. The hopper system enables the marbles to align in a single-file line in order to move them into the receiver channel smoothly under the influence of gravity. The function of the separation system is to separate the marbles so that they fall into the testing chamber, one at a time. The sensing system, which consists of a lamp and a photo resistor, detects the colors of the marbles, and its readings are used to determine which bin to move. The sensing system operates the trap door system as well. The marble falls into the bin under the control of a trap door mounted at the bottom of the testing chamber.

In the bridge design project, students used knowledge of material properties and the effects of stress to design and construct a bridge made from balsa wood. The goal of the project was to design and build a bridge that can hold the largest load while minimizing the bridge weight. The bridge design activity requires a problem solving approach which emphasizes the analysis aspect of the engineering design process. Prior to designing and building their bridge, students learn about the strength of materials through a hands-on tensile testing activity, learn to solve free body diagram, and stimulate structures through a variety of software packages. Through the design analysis process, students have predictive design solution prior to building their design.

The students were required to work in small groups to finish the project on their own. Each group needed to figure out how to design and construct the device. While the group members had different ideas on how to build the sorter, another objective was to resolve conflicts and agree on the most logical solution to the project. In addition to gaining hands-on experience in engineering, they learned to work in a team where each member's knowledge and skills were used to the best advantage. They needed to combine their strengths to achieve the objective. During the project, the students learned how to cooperate and compete with others to achieve deadlines, budgets, communication, and interpersonal relationships.

The Study

Research Questions

One broad research question was constructed to guide this study: How do analysis-focused and creative trial-and-error-focused design activities impact students' motivation?

Study Participants

One hundred twenty three students from five high schools participated in the study. These schools implement Project Lead the Way curriculum and were located in Indiana, Missouri, and Utah. One hundred and four students completed the EDQ for marble-sorter design, and 53 students completed EDQ for bridge design. Among the five schools, only two had successfully completed both marble-sorter and bridge design activities, and only 34 students completed both EDQ surveys.

Instrumentation

This study utilized an Engineering Design Questionnaires (EDQ) survey instrument to assess student's motivation. Two versions of EDQ (i.e., EDQ-Bridge Design and EDQ-Marble-Sorter Design) were used in this study. Basically, those two versions are identical, except the instruction provided in each version was specifically made to reflect each type of design activity (i.e., Bridge Design, Marble-Sorter Design). A statement such as "Please think of your marble-sorter design activity while reading these statements," or "Please think of your bridge design activity while reading these statements" was used. The motivational scales in EDQ were taken from the Motivated Strategies for Learning Questionnaire (MSLQ) survey instrument. Five demographic and two open-ended questions were added in both versions of the EDQ to provide additional information about each student.

The Motivated Strategies for Learning Questionnaire (MSLQ) is a self-report instrument developed by Pintrich, Smith, Garcia, and McKeachie (1991) to assess college students' motivational orientations and their use of different learning strategies for a college course. Although MSLQ is designed for a college course, the researchers chose this instrument for three reasons: (1) This is the only instrument available that measures motivation with the value and expectancy components; (2) This instrument has been widely used in educational research in college and lower-level education courses; (3) Because the course in which the study participants enrolled (i.e. Principle of Engineering) is college credit equivalent, it was expected that statements in this survey would be understood by sophomore and junior high school students.

Validation of the MSLQ and the subscale correlations with final grades were significant, demonstrating predictive validity. Confirmatory factor analyses tested how closely the input correlations could be reproduced given the constraints that specific items fall on. All of the 31 motivation items were tested to see how well they fit the latent factors. The Cronbach's alpha coefficients were robust, ranging from .52 to .93. Lambda-ksi estimates of the MSLQ, which are analogous to factor loadings in an exploratory factor analysis, indicated well-defined latent constructs.

Only the motivational scales (i.e., 26 items) were used in this study. Those motivational scales included five components. First, the instrument is composed of statements that measure the student's perception of the reason he or she is engaging in the learning task, an Intrinsic Goal Orientation-IGO (alpha = 0.74). Second, statements measure the degree to which the student perceives him or herself to be participating in the task for extrinsic reasons, an Extrinsic Goal Orientation-EGO (alpha = 0.62). Third, statements are present that measure each student's perception of how important, useful, and interesting the task is, a Task value-TV (alpha = 0.90). Fourth, statements are present that measure the student's beliefs that his or her efforts to learn will result in positive outcomes, a Control Beliefs-CB (alpha = 0.68). Fifth, statements are present that measure each student's expectation to perform the task well and to be self-efficient, a Self-Efficacy for Learning and Performance-SELP (alpha = 0.93). Students rated themselves on a 7-point Likert scale, from "not at all true of me" (a score of 1) to "very true of me" a score of 7.

Data Collection and Analysis

Selected PLTW schools that require their students to engage in two different types of engineering design activities using two distinct design approaches were invited to participate in this study. Data collection process started immediately after the approval from the Office of Human Subjects Research at the Utah State University. Each student was asked to fill out the survey twice. After completing each design activity, each student was asked to fill out the survey instrument. Their POE teachers administered the survey.

On the cover page of the each set of the survey instrument, students were asked to write their names. Each student at each school was assigned one unique ID number. For example, school ABC was coded with a number of "1", and the students were coded with a number of "01" through "99." Thus, the unique ID number for student "01" was "101." The list of the students' name and the completed survey instruments were stored securely in two separate locations. As soon as all survey instruments were collected, these unique ID numbers were written on the instrument and the cover page was removed and destroyed. Due to the sensitive nature of the data collected, no other identification was included in the survey instruments, and only the PI had access to the data. Students were asked to respond to all survey items. Only 34 completed survey instruments were analyzed.

Data collected from each subscale of EDQ (i.e., IGO, EGO, TV, CB, and SELP), and the student ID were entered into SPSS. Frequency count and the percentage of demographic information of the students were also calculated. The mean and standard deviation of students' overall motivation (Mot): IGO, EGO, TV, CB, and SELP were calculated. To determine whether motivation differences existed between the two distinct design activities and to evaluate students' motivation across five demographic groups, two-tailed t-tests and one-way Analysis of Variance (ANOVA) tests were conducted. Pearson correlation tests were also conducted to find any correlation between the five motivational aspects. As it is for open-ended questions, common themes and frequency count for each theme were coded.

Results

Study Participant Profiles

From those 34 students, demographic information was collected and is presented in Tables 1 - 5 below.

Table 1. Demographic - Gender

	Frequency	Percent (%)
Male	31	91.2
Female	3	8.8

Table 2. Demographic - Ethnic

	Frequency	Percent (%)
African American	0	0
Asian-Pacific Islander	3	8.8
Caucasian	30	88.2
Hispanic	0	0
Native American	0	0
Other	1	2.9

Table 3. Demographic - Class Level

	Frequency	Percent (%)
Freshman	0	0
Sophomore	26	76.5
Junior	7	20.6
Senior	1	2.9

Table 4. Demographic - Highest Level of Math Course

	Frequency	Percent (%)
Algebra 1	0	0
Geometry	10	29.4
Algebra 2	13	38.2
Trigonometry/Pre-Calculus	8	23.5
Calculus	0	0
AP Calculus	0	0
None	0	0

Table 5. Demographic - Considering Engineering/Technology School

	Frequency	Percent (%)
Yes	26	76.5
No	8	23.5

Students' Motivation

A. Descriptive Statistics of Students' Motivation

The descriptive statistics show that the mean of students' overall motivation (i.e., Mot) and other motivational aspects (except for EGO) are higher during Bridge Design than Marble-Sorter Design (see Table 6). Although the difference between the means may seem relatively small, the t-test conducted in Part B shows that the change in students' intrinsic goal orientation (IGO) during the two design activities is significant.

Table 6. Descriptive Statistics of Students' Motivation

	Marble sorter		Bridge	
	Mean	SD	Mean	SD
Mot	5.47	.98	5.59	1.07
IGO	5.10	1.23	5.48	1.39
EGO	5.88	.82	5.85	.91
TV	5.38	1.35	5.44	1.41
CB	5.35	1.26	5.50	1.30
SELP	5.57	1.17	5.70	1.21

B. Students' Motivation During Marble Sorter and Bridge Design Activities

Six paired-t-tests were conducted to determine if there was any significant difference of students' motivation while engaged in Marble Sorter and Bridge Design activities. The statistical tests were conducted in two stages: evaluating students' overall motivation (i.e., Mot) and students' IGO, EGO, TV, SELP, and CB. The results show that there was (see Table 7 and 8):

- no significant difference in students' overall motivation (Mot), $t(34) = -1.25$, $p > .05$
- a significant difference in students' intrinsic goal orientation (IGO), $t(34) = -2.58$, $p < .05$
- no significant difference in students' extrinsic goal orientation (EGO), $t(34) = .20$, $p > .05$
- no significant difference in students' task value (TV), $t(34) = -.42$, $p > .05$
- no significant difference in students' self-efficacy (SELP), $t(34) = -1.10$, $p > .05$
- no significant difference in students' control belief (CB), $t(34) = -.86$, $p > .05$

Table 7. Paired-t-test - Students' Overall Motivation

	t	df	Sig. (2-tailed)
Pair Mot_MSD – Mot_BD	-1.25	33	.221

Table 8. Paired-t-test - Students' IGO, EGO, TV, SELP, CB

		t	df	Sig. (2-tailed)
Pair 1	IGO_MSD – IGO_BD	-2.58	33	.015
Pair 2	EGO_MSD – EGO_BD	.20	33	.846
Pair 3	TV_MSD – TV_BD	-.42	33	.679
Pair 4	SELP_MSD – SELP_BD	-1.10	33	.278
Pair 5	CB_MSD – CB_BD	-.86	33	.397

C. Students' motivation viewed from some demographic information

Five series of one-way ANOVA tests were conducted to evaluate if there was any significant change of students' overall motivation (Mot) while engaged in MSD and BD activities across five demographic groups (i.e., gender, ethnic background, class level, highest level of math courses taken, and considering majoring in engineering or technology in college). Evaluations of students' EGO, IGO, TV, SELP, and CB on both marble sorter and bridge design activities were also conducted in each of these series of tests.

C.1. *Gender*. The results show that while engaged in marble sorter (MSD) and bridge designs (BD), there was no significant difference in students' (see Table 9):

- overall motivation (i.e., Mot) during MSD, $F(1, 32) = .05$, $p > .05$, and during BD, $F(1,32) = .22$, $p > .05$
- intrinsic goal orientation (IGO) during MSD, $F(1, 32) = .07$, $p > .05$, and during BD, $F(1, 32) = .03$, $p > .05$
- extrinsic goal orientation (EGO) during MSD, $F(1, 32) = .08$, $p > .05$, and during BD, $F(1, 32) = 3.75$, $p > .05$
- task value (TV) during MSD, $F(1, 32) = .13$, $p > .05$, and during BD, $F(1, 32) = .18$, $p > .05$
- self-efficacy (SELP) during MSD, $F(1, 32) = .38$, $p > .05$, and during BD, $F(1, 32) = .02$, $p > .05$
- control belief (CB) during MSD, $F(1, 32) = 1.13$, $p > .05$, and during BD, $F(1, 32) = .33$, $p > .05$

C.2. *Ethnic background*. The results show that while engaged in marble sorter (MSD) and bridge designs (BD), there was no significant difference in students' (see Table 10):

- overall motivation (i.e., Mot) during MSD, $F(2, 31) = .75$, $p > .05$, and during BD, $F(2,31) = .31$, $p > .05$
- intrinsic goal orientation (IGO) during MSD, $F(2, 31) = .44$, $p > .05$, and during BD, $F(2, 31) = .16$, $p >.05$
- extrinsic goal orientation (EGO) during MSD, $F(2, 31) = .10$, $p > .05$, and during BD, $F(2, 31) = .11$, $p >.05$
- task value (TV) during MSD, $F(2, 31) = .56$, $p > .05$, and during BD, $F(2, 31) = .38$, $p >.05$
- self-efficacy (SELP) during MSD, $F(2, 31) = 1.04$, $p > .05$, and during BD, $F(2, 31) = .44$, $p >.05$
- control belief (CB) during MSD, $F(2, 31) = .33$, $p > .05$, and during BD, $F(2, 31) = .23$, $p >.05$

C.3. *Class level*. The results show that while engaged in marble sorter (MSD) and bridge designs (BD), there was no significant difference in students' (see Table 11):

- overall motivation (i.e., Mot) during MSD, $F(2, 31) = .25$, $p > .05$, and during BD, $F(2,31) = .23$, $p > .05$
- intrinsic goal orientation (IGO) during MSD, $F(2, 31) = .13$, $p > .05$, and during BD, $F(2, 31) = 1.03$, $p > .05$

- extrinsic goal orientation (EGO) during MSD, $F(2, 31) = .75$, $p > .05$, but there was a significant difference in students' EGO during BD, $F(2, 31) = 7.52$, $p < .05$
- task value (TV) during MSD, $F(2, 31) = 1.09$, $p > .05$, and during BD, $F(2, 31) = .28$, $p > .05$
- self-efficacy (SELP) during MSD, $F(2, 31) = .20$, $p > .05$, and during BD, $F(2, 31) = .47$, $p > .05$
- control belief (CB) during MSD, $F(2, 31) = .35$, $p > .05$, and during BD, $F(2, 31) = .22$, $p > .05$

C.4. *Highest level of math courses taken*. The results show that while engaged in marble sorter (MSD) and bridge designs (BD), there was no significant difference in students' (see Table 12):

- overall motivation (i.e., Mot) during MSD, $F(2, 28) = .32$, $p > .05$, and during BD, $F(2,28) = .30$, $p > .05$
- intrinsic goal orientation (IGO) during MSD, $F(2, 28) = .73$, $p > .05$, and during BD, $F(2, 28) = .28$, $p > .05$
- extrinsic goal orientation (EGO) during MSD, $F(2, 28) = .02$, $p > .05$, and during BD, $F(2, 28) = 1.19$, $p > .05$
- task value (TV) during MSD, $F(2, 28) = .34$, $p > .05$, and during BD, $F(2, 28) = .90$, $p >.05$
- self-efficacy (SELP) during MSD, $F(2, 28) = .61$, $p > .05$, and during BD, $F(2, 28) = .41$, $p > .05$
- control belief (CB) during MSD, $F(2, 28) = .32$, $p > .05$, and during BD, $F(2, 28) = .25$, $p > .05$

C.5. *Considering majoring in engineering or technology in college*. The results show that while engaged in marble sorter (MSD) and bridge designs (BD), there was (see Table 13):

- a significant difference in students' overall motivation (i.e., Mot) during MSD, $F(1, 32) = 23.19$, $p < .01$, and during BD, $F(1,32) = 15.43$, $p < .01$
- a significant difference in students' intrinsic goal orientation (IGO) during MSD, $F(1, 32) = 13.36$, $p < .01$, and during BD, $F(1, 32) = 6.86$, $p < .05$
- no significant difference in students' extrinsic goal orientation (EGO) during MSD, $F(1, 32) = 1.62$, $p > .05$, and during BD, $F(1, 32) = 1.31$, $p >.05$
- a significant difference in students' task value (TV) during MSD, $F(1, 32) = 20.92$, $p < .01$, and during BD, $F(1, 32) = 11.16$, $p < .01$
- a significant difference in students' self-efficacy (SELP) during MSD, $F(1, 32) = 23.42$, $p < .01$, and during BD, $F(1, 32) = 21.23$, $p < .01$
- a significant difference in students' control belief (CB) during MSD, $F(1, 32) = 5.32$, $p < .05$, and during BD, $F(1, 32) = 9.17$, $p < .01$

Table 9: One-Way ANOVA - Gender

		Sum of Squares	df	Mean Square	F	Sig.
Mot_MSD	Between Groups	.05	1	.05	.05	.829
	Within Groups	31.37	32	.98		
	Total	31.42	33			
IGO_MSD	Between Groups	.11	1	.11	.07	.797
	Within Groups	50.15	32	1.57		
	Total	50.25	33			
EGO_MSD	Between Groups	.06	1	.06	.08	.775
	Within Groups	22.22	32	.69		
	Total	22.28	33			
TV_MSD	Between Groups	.24	1	.24	.13	.722
	Within Groups	59.81	32	1.87		
	Total	60.05	33			
SELP_MSD	Between Groups	.53	1	.53	.38	.543
	Within Groups	44.42	32	1.39		
	Total	44.95	33			
CB_MSD	Between Groups	1.79	1	1.79	1.13	.296
	Within Groups	50.71	32	1.59		
	Total	52.50	33			
Mot_BD	Between Groups	.25	1	.25	.22	.645
	Within Groups	37.66	32	1.18		
	Total	37.92	33			
IGO_BD	Between Groups	.07	1	.07	.03	.854
	Within Groups	64.10	32	2.00		
	Total	64.17	33			
EGO_BD	Between Groups	2.88	1	2.88	3.75	.062
	Within Groups	24.63	32	.77		
	Total	27.52	33			
TV_BD	Between Groups	.36	1	.36	.18	.678
	Within Groups	65.36	32	2.04		
	Total	65.72	33			
SELP_BD	Between Groups	.03	1	.03	.02	.892
	Within Groups	48.17	32	1.51		
	Total	48.19	33			
CB_BD	Between Groups	.57	1	.57	.33	.572
	Within Groups	55.40	32	1.73		
	Total	55.97	33			

Table 10: One-Way ANOVA - Ethnic Background

		Sum of Squares	df	Mean Square	F	Sig.
Mot_MSD	Between Groups	1.44	2	.72	.75	.481
	Within Groups	29.97	31	.97		
	Total	31.42	33			
IGO_MSD	Between Groups	1.38	2	.69	.44	.651
	Within Groups	48.88	31	1.58		
	Total	50.25	33			
EGO_MSD	Between Groups	.15	2	.07	.10	.903
	Within Groups	22.13	31	.71		
	Total	22.28	33			
TV_MSD	Between Groups	2.08	2	1.04	.56	.58
	Within Groups	57.96	31	1.87		
	Total	60.05	33			
SELP_MSD	Between Groups	2.82	2	1.41	1.04	.366
	Within Groups	42.12	31	1.36		
	Total	44.95	33			
CB_MSD	Between Groups	1.09	2	.55	.33	.722
	Within Groups	51.41	31	1.66		
	Total	52.50	33			
Mot_BD	Between Groups	.74	2	.37	.31	.736
	Within Groups	37.18	31	1.20		
	Total	37.92	33			
IGO_BD	Between Groups	.67	2	.33	.16	.850
	Within Groups	63.50	31	2.05		
	Total	64.17	33			
EGO_BD	Between Groups	.19	2	.10	.11	.90
	Within Groups	27.33	31	.88		
	Total	27.52	33			
TV_BD	Between Groups	1.56	2	.78	.38	.688
	Within Groups	64.15	31	2.07		
	Total	65.72	33			
SELP_BD	Between Groups	1.32	2	.66	.44	.650
	Within Groups	46.87	31	1.51		
	Total	48.19	33			
CB_BD	Between Groups	.83	2	.42	.23	.79
	Within Groups	55.13	31	1.78		
	Total	55.97	33			

Table 11: One-Way ANOVA - Class Level

		Sum of Squares	df	Mean Square	F	Sig.
Mot_MSD	Between Groups	.50	2	.25	.25	.781
	Within Groups	30.92	31	1.00		
	Total	31.42	33			
IGO_MSD	Between Groups	.41	2	.21	.13	.881
	Within Groups	49.84	31	1.61		
	Total	50.25	33			
EGO_MSD	Between Groups	1.03	2	.51	.75	.481
	Within Groups	21.25	31	.69		
	Total	22.28	33			
TV_MSD	Between Groups	3.96	2	1.98	1.09	.348
	Within Groups	56.09	31	1.81		
	Total	60.05	33			
SELP_MSD	Between Groups	.57	2	.28	.20	.822
	Within Groups	44.38	31	1.43		
	Total	44.95	33			
CB_MSD	Between Groups	1.15	2	.57	.35	.711
	Within Groups	51.36	31	1.66		
	Total	52.50	33			
Mot_BD	Between Groups	.56	2	.28	.23	.795
	Within Groups	37.36	31	1.21		
	Total	37.92	33			
IGO_BD	Between Groups	3.99	2	2.00	1.03	.369
	Within Groups	60.18	31	1.94		
	Total	64.17	33			
EGO_BD	Between Groups	8.99	2	4.50	7.52	.002
	Within Groups	18.52	31	.60		
	Total	27.52	33			
TV_BD	Between Groups	1.18	2	.59	.28	.756
	Within Groups	64.54	31	2.08		
	Total	65.72	33			
SELP_BD	Between Groups	1.43	2	.71	.47	.628
	Within Groups	46.77	31	1.51		
	Total	48.19	33			
CB_BD	Between Groups	.80	2	.40	.22	.801
	Within Groups	55.17	31	1.78		
	Total	55.97	33			

Table 12: One-Way ANOVA – Highest Level of Math Courses Taken

		Sum of Squares	df	Mean Square	F	Sig.
Mot_MSD	Between Groups	.68	2	.34	.32	.731
	Within Groups	29.88	28	1.07		
	Total	30.56	30			
IGO_MSD	Between Groups	2.37	2	1.18	.73	.492
	Within Groups	45.52	28	1.63		
	Total	47.89	30			
EGO_MSD	Between Groups	.02	2	.01	.02	.985
	Within Groups	20.10	28	.72		
	Total	20.12	30			
TV_MSD	Between Groups	1.40	2	.70	.34	.713
	Within Groups	57.32	28	2.05		
	Total	58.72	30			
SELP_MSD	Between Groups	1.85	2	.93	.61	.552
	Within Groups	42.70	28	1.53		
	Total	44.55	30			
CB_MSD	Between Groups	1.13	2	.56	.32	.73
	Within Groups	49.04	28	1.75		
	Total	50.17	30			
Mot_BD	Between Groups	.73	2	.36	.30	.746
	Within Groups	34.43	28	1.23		
	Total	35.16	30			
IGO_BD	Between Groups	1.18	2	.59	.28	.761
	Within Groups	59.80	28	2.14		
	Total	60.98	30			
EGO_BD	Between Groups	1.99	2	.99	1.19	.318
	Within Groups	23.31	28	.83		
	Total	25.29	30			
TV_BD	Between Groups	3.71	2	1.85	.90	.417
	Within Groups	57.57	28	2.06		
	Total	61.28	30			
SELP_BD	Between Groups	1.32	2	.66	.41	.670
	Within Groups	45.34	28	1.62		
	Total	46.66	30			
CB_BD	Between Groups	.89	2	.45	.25	.785
	Within Groups	51.15	28	1.83		
	Total	52.05	30			

Table 13: One-Way ANOVA - Considering Majoring in Engineering or Technology

		Sum of Squares	df	Mean Square	F	Sig.
Mot_MSD	Between Groups	13.20	1	13.20	23.19	.000
	Within Groups	18.22	32	.57		
	Total	31.42	33			
IGO_MSD	Between Groups	14.80	1	14.80	13.36	.001
	Within Groups	35.45	32	1.11		
	Total	50.25	33			
EGO_MSD	Between Groups	1.07	1	1.07	1.62	.213
	Within Groups	21.21	32	.66		
	Total	22.28	33			
TV_MSD	Between Groups	23.74	1	23.74	20.92	.000
	Within Groups	36.31	32	1.14		
	Total	60.05	33			
SELP_MSD	Between Groups	18.99	1	18.99	23.42	.000
	Within Groups	25.95	32	.81		
	Total	44.95	33			
CB_MSD	Between Groups	7.48	1	7.48	5.32	.028
	Within Groups	45.02	32	1.41		
	Total	52.50	33			
Mot_BD	Between Groups	12.34	1	12.34	15.43	.000
	Within Groups	25.58	32	.80		
	Total	37.92	33			
IGO_BD	Between Groups	11.33	1	11.33	6.86	.013
	Within Groups	52.85	32	1.65		
	Total	64.17	33			
EGO_BD	Between Groups	1.08	1	1.08	1.31	.261
	Within Groups	26.43	32	.83		
	Total	27.52	33			
TV_BD	Between Groups	16.99	1	16.99	11.16	.002
	Within Groups	48.72	32	1.52		
	Total	65.72	33			
SELP_BD	Between Groups	19.22	1	19.22	21.23	.000
	Within Groups	28.97	32	.91		
	Total	48.19	33			
CB_BD	Between Groups	12.46	1	12.46	9.17	.005
	Within Groups	43.51	32	1.36		
	Total	55.97	33			

D. Correlations between Students' IGO, EGO, TV, SELP, CB

This part includes additional statistical tests that were conducted to evaluate how IGO, EGO, TV, SELP, and CB interacted among students while working on an engineering design. Interactions among these motivation elements were evaluated by conducting a series of correlation tests. The results show that there was (see Table 14 - 23):

- a significant correlation between students' intrinsic goal orientation (IGO) and control belief (CB) during the MSD project, $r(34) = .65$, $p < .01$, and during the BD project, $r(34) = .72$, $p < .01$
- a significant correlation between students' intrinsic goal orientation (IGO) and task value (TV) during the MSD project, $r(34) = .87$, $p < .01$, and during the BD project, $r(34) = .91$, $p < .01$
- a significant correlation between students' intrinsic goal orientation (IGO) and self-efficacy (SELP) during the MSD project, $r(34) = .74$, $p < .01$, and during the BD project, $r(34) = .83$, $p < .01$
- no significant correlation between students' intrinsic goal orientation (IGO) and extrinsic goal orientation (EGO) during the MSD project, $r(34) = .24$, $p > .05$, and during the BD project, $r(34) = .09$, $p > .05$
- a significant correlation between students' control belief (CB) and task value (TV) during the MSD project, $r(34) = .69$, $p < .01$, and during the BD project, $r(34) = .78$, $p < .01$
- a significant correlation between students' control belief (CB) and self-efficacy (SELP) during the MSD project, $r(34) = .74$, $p < .01$, and during the BD project, $r(34) = .87$, $p < .01$
- no significant correlation between students' control belief (CB) and extrinsic goal orientation (EGO) during the MSD project, $r(34) = .08$, $p > .05$, and during the BD project, $r(34) = .05$, $p > .05$
- a significant correlation between students' task value (TV) and self efficacy (SELP) during the MSD project, $r(34) = .79$, $p < .01$, and during the BD project, $r(34) = .84$, $p < .01$
- no significant correlation between students' task value (TV) and extrinsic goal orientation (EGO) during the MSD project, $r(34) = .12$, $p > .05$, and during the BD project, $r(34) = .30$, $p > .05$
- no significant correlation between students' self efficacy (SELP) and extrinsic goal orientation (EGO) during the MSD project, $r(34) = -.02$, $p > .05$, and during the BD project, $r(34) = .07$, $p > .05$

Table 14: Correlation - IGO and CB

		CB_MSD	CB_BD
IGO_MSD	Pearson Correlation	.652	
	Sig. (2-tailed)	.000**	
	N	34	
IGO_BD	Pearson Correlation		.722
	Sig. (2-tailed)		.000**
	N		34

**Correlation is significant at the 0.01 level (2-tailed)

Table 15: Correlation - IGO and TV

		TV_MSD	TV_BD
IGO_MSD	Pearson Correlation	.874	
	Sig. (2-tailed)	.000**	
	N	34	
IGO_BD	Pearson Correlation		.909
	Sig. (2-tailed)		.000**
	N		34

**Correlation is significant at the 0.01 level (2-tailed)

Table 16: Correlation - IGO and SELP

		SELP_MSD	SELP_BD
IGO_MSD	Pearson Correlation	.742	
	Sig. (2-tailed)	.000**	
	N	34	
IGO_BD	Pearson Correlation		.825
	Sig. (2-tailed)		.000**
	N		34

**Correlation is significant at the 0.01 level (2-tailed)

Table 17: Correlation - IGO and EGO

		EGO_MSD	EGO_BD
IGO_MSD	Pearson Correlation	.243	
	Sig. (2-tailed)	.166	
	N	34	
IGO_BD	Pearson Correlation		.090
	Sig. (2-tailed)		.614
	N		34

Table 18: Correlation - CB and TV

		TV_MSD	TV_BD
CB_MSD	Pearson Correlation	.691	
	Sig. (2-tailed)	.000**	
	N	34	
CB_BD	Pearson Correlation		.779
	Sig. (2-tailed)		.000**
	N		34

**Correlation is significant at the 0.01 level (2-tailed)

Table 19: Correlation - CB and SELP

		SELP_MSD	SELP_BD
CB_MSD	Pearson Correlation	.736	
	Sig. (2-tailed)	.000**	
	N	34	
CB_BD	Pearson Correlation		.865
	Sig. (2-tailed)		.000**
	N		34

**Correlation is significant at the 0.01 level (2-tailed)

Table 20: Correlation - CB and EGO

		EGO_MSD	EGO_BD
CB_MSD	Pearson Correlation	.084	
	Sig. (2-tailed)	.636	
	N	34	
CB_BD	Pearson Correlation		.049
	Sig. (2-tailed)		.784
	N		34

Table 21: Correlation - TV and SELP

		SELP_MSD	SELP_BD
TV_MSD	Pearson Correlation	.789	
	Sig. (2-tailed)	.000**	
	N	34	
TV_BD	Pearson Correlation		.840
	Sig. (2-tailed)		.000**
	N		34

**Correlation is significant at the 0.01 level (2-tailed)

Table 22: Correlation - TV and EGO

		EGO_MSD	EGO_BD
TV_MSD	Pearson Correlation	.117	
	Sig. (2-tailed)	.511	
	N	34	
TV_BD	Pearson Correlation		.298
	Sig. (2-tailed)		.087
	N		34

Table 23: Correlation - SELP and EGO

		EGO_MSD	EGO_BD
SELP_MSD	Pearson Correlation	-.016	
	Sig. (2-tailed)	.927	
	N	34	
SELP_BD	Pearson Correlation		.074
	Sig. (2-tailed)		.677
	N		34

E. Common Themes of Students' Motivation

A total of 104 and 53 students total responded to the two open-ended questions in the survey instrument after finishing their marble-sorter and bridge designs, respectively. From those, only 34 students completed both surveys. Students were asked to share their thoughts about the three most and least motivating experiences during their marble sorter and bridge design activities. Common themes were categorized according to the five motivation elements (i.e., IGO, EGO, TV, SELP, and CB) (see Table 24-27). No single theme was found for Control

Belief. In addition, there were few responses that could not be included into those five motivation categories.

Common themes associated with

- IGO includes
    - Hands-on experience[M]: associated with a practical activity, such as building, programming, etc.
    - Mastery[M]: associated with activities that help students master one particular skill, such as learning how to solve problems, run program, etc.
    - Task challenge[M,L]: associated with activities that challenge students, such as difficulty in programming.
    - Time challenge[M,L]: associated with limited time available to students.
    - Plenty of time available[M]
    - Administrative challenge[L]: associated with administrative tasks, such as writing a report, presentation, etc.
    - Lack of challenge[L]: associated with a situation where a student feels there is not enough challenge.
- EGO includes
    - Successful performance[M]: associate with task outcome or progress, such as getting a task done or work.
    - Getting a good grade[M]
    - Comparison and competition[M]: associated with a desire to compare results or perform better than others, such as trying to make the design faster
    - Good teamwork[M]
    - Evaluation by others[M]
    - Teacher assistance[M]
    - Supporting materials[M,L]: associated with the availability, unavailability, or the level of difficulty in use of supporting materials, such knife, glue, etc.
    - Failure or poor performance[L]
    - Bad teamwork[L]
    - Lack of instruction and teacher assistance[L]
    - Getting an unsatisfactory grade[L]
    - Competition[L]
- TV includes
    - Interest in the content or project[M]
    - Lack of interest[L]
    - Lack of opportunity to reengage in the project[L]: associated with the fact that students would not be able to engage in similar projects during their school year
- SELP includes
    - Ability to master[M]
    - Expectancy for success[M]
    - Lack of ability to master[L]
    - Lack of expectance for success[L]

The superscript “M” indicates themes associated with the most motivating aspect, and “L” indicates themes associated with the least motivating aspect on the marble sorter design or bridge design projects. Common themes and the frequency count for each theme were coded from all students from five schools. The frequency count for each theme is presented between parentheses. The first number represents the number of students, from all schools, who selected a particular theme, while the second number represents the number of students from the two schools that had completed both design activities. For purpose of comparing the count, only the frequency count represented by the second number was used (see Table 28).

Table 24: Common Themes - Most Motivating on Marble Sorter Design

Category	Common Theme (frequency)
Intrinsic Goal Orientation (IGO)	Participation or hands on experience (42, 9), Mastery (27, 3), Task challenge or problem (19, 4), Time challenge (5, 3)
Extrinsic Goal orientation (EGO)	Successful performance (81, 33), Getting a good grade (32, 14), Comparison and competition (21, 9), Good teamwork (18, 4), Evaluation by others (6, 2), Teacher assistance (4, 0)
Task Value (TV)	Interest in the content or project (12, 6)
Self Efficacy (SELP)	Ability to master (4, 2), Expectancy for success (3, 2)

Table 25: Common Themes - Most Motivating on Bridge Design

Category	Common Theme (frequency)
Intrinsic Goal Orientation (IGO)	Participation or hand on experience (31, 16), Task challenge or problem (13, 11), Mastery (12, 7), Plenty of time available (4, 2)
Extrinsic Goal orientation (EGO)	Getting a good grade (27, 15), Comparison and competition (16, 13), Good teamwork (8, 5), Successful performance (13, 11), Teacher assistance (4, 3), Supporting materials (1, 0)
Task Value (TV)	Interest in the content or the project (16, 10)
Self Efficacy (SELP)	Ability to master (2, 1), Expectancy for success (1, 0)

Table 26: Common Themes - Least Motivating on Marble Sorter Design

Category	Common Theme (frequency)
Intrinsic Goal Orientation (IGO)	Task challenge or problem (105, 36), Time challenge (23, 9), Administrative challenge (17, 7), Lack of challenge (1, 0)
Extrinsic Goal orientation (EGO)	Failure or poor performance (66, 20), Bad teamwork (26, 12), Lack of instruction and teacher assistance (4, 1), Getting an unsatisfactory grade (1, 0)
Task Value (TV)	Lack of interest (10, 1)
Self Efficacy (SELP)	Lack of ability to master (12, 4)

Table 27: Common Themes - Least Motivating on Bridge Design

Category	Common Theme (frequency)
Intrinsic Goal Orientation (IGO)	Task challenge or problem (58, 42), Time challenge (15, 10), Administrative challenge (3, 1)
Extrinsic Goal orientation (EGO)	Bad teamwork (13, 5), Competition (5, 2), Failure or poor performance (20, 14), Getting an unsatisfactory grade (4, 2), Lack of instruction (2, 2), Supporting materials (8, 5)
Task Value (TV)	Lack of interest (6, 6), Lack of opportunity to reengage in the project (1, 1)
Self Efficacy (SELP)	Lack of expectancy for success (1, 1), Lack of ability to master (3, 3)
Other	Unrecognizable handwriting (2, 1), Unclassifiable response (1, 1)

Table 28: Comparison of Most and Least Motivating Factors

	Most Motivating Factors		Least Motivating Factors	
	Marble Sorter Design (MSD)	Bridge Design (BD)	Marble Sorter Design (MSD)	Bridge Design (BD)
Intrinsic Goal Orientation (IGO)	19	36	52	53
Extrinsic Goal Orientation (EGO)	62	47	33	30
Task Value (TV)	6	10	1	7
Self-Efficacy (SELP)	4	1	4	4

Discussion and Future Study

The results of this study suggest that students are more intrinsically motivated when working on a design task that require them to engage in an engineering design process as in that which was required by the bridge design project. This finding was confirmed by the results found from the responses to the open-ended questions. Themes associated with the intrinsic motivation were frequently identified on bridge than marble-sorter designs. It is also interesting to note that students identified more intrinsic motivation issues on the bridge than on the marble-sorter design. In contrast, themes associated with students' extrinsic motivation were identified more frequently on marble-sorter than bridge designs.

The design process in engineering entails a systematic way of developing conceived solutions through steps such as defining a problem, conceptualizing the design, making a preliminary design, detailing the design, communicating the design, and finalizing the design (Dym & Little, 2000). Technological problem solving, on the other hand, includes six steps that are somewhat different than engineering design procedure. It includes defining the problem, developing alternative solutions, selecting a solution, implementing and evaluating the solution, redesigning the solution, and interpreting the solution (Barnes, 1989; Hutchinson, 1987; Waetjen, 1989). In many of these steps, the use of a working technique that involves modification and/or combination ideas from the collection of possible solutions is dominant. Prior to conducting this study, it was expected that students would be more motivated when working on the marble-sorter design because it was related more to technological problem solving than an engineering design task. The significant change in students' intrinsic motivation was not expected.

From the common themes that are associated with students' intrinsic motivation, it appears that students felt that bridge design required more participation or hands-on experience, required more knowledge and skills on their part, and was more challenging. These factors might intrinsically drive students to be more motivated when working on the bridge design rather than the marble sorter design projects. When we evaluated all of the themes associated with the motivational aspects, it was clear that these students had included all critical features of engineering design (Asunda & Hill, 2007) that are essential in engineering and technology education. Students were readily able to identify the process of engineering education, attributes of engineering design, and assessment in their responses regarding the most and least motivating factors about their projects.

Despite the limited number of data set gathered and analyzed in this study, a potential topic for our future research may be associated with our effort to answer a general question like: How does student motivation influence the cognitive processes during engineering design activities? This question may lead us to several more specific questions, including what specific metacognitive and task process are employed to meet the design goals.

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