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Understanding of Student Task Interpretation, Design Planning, and Cognitive Strategies during Engineering Design Activities in Grades 9-12

National Center for Engineering and Technology Education
Final Report

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Abstract

The objective of this study was to describe the task interpretation of students engaged in a design activity and determine the extent to which students translate their understanding of their design task to their planning and cognitive strategies. Twenty-nine students at one Colorado high school participated in this study. Students worked individually in the Architectural Design class (*n*=7), and in teams in the Robotics Design class (*n*=22). To capture students' perceptions of their understanding of the task, planning strategies, and cognitive strategies, the Engineering Design Questionnaire (EDQ) was used. The development of the EDQ was guided by Butler and Cartier's Self-Regulated Learning (SRL) model. Besides the EDQ, a Web-based Engineering Design Notebook was developed to facilitate students reporting planning activities and engineering design strategies.

Graphical views are used to present quantitative and qualitative analysis of data collected in this study. In addition, the mean scores of design phases (i.e., SRL dimensions) were compared across SRL features (i.e., task interpretation, planning strategies, and cognitive strategies). From the analysis, the findings suggest that the level of understanding of the task were high in problem definition, conceptual design, and preliminary design. In contrast, students were found to be lacking on those three design process components in the area of planning strategies. Students performed well in cognitive strategies except for problem definition.

I. Introduction

The Committee on K-12 Engineering Education (Katehi, Pearson, & Feder, 2009) suggested that K-12 engineering education should emphasize engineering design. Everett, Imbrie, and Morgan (2000) noted that through the engineering design process "students not only know the mathematics and science but also actually understand why they need to know it" (p. 171). In addition to the needs of engineering and technology, metacognition is essential in both mathematics (Carr & Biddlecomb, 1998; Schoenfeld, 1992) and science (Georgiades, 2000; Rickey & Stacey, 2000).

This exploratory study specifically focuses on student task understanding and its relation to planning and cognitive strategies in engineering design activity. Student task understanding, or called task interpretation, is one of the metacognitive features and the heart of the self-regulated learning (SRL) model insofar as it shapes key dynamic and recursive self-regulating processes. Butler (1998) found that having a good understanding of a presented learning activity grounded in productive metacognitive knowledge about tasks is associated with students' thoughtful planning, self monitoring, and selection of appropriate strategies to accomplish task objectives.

In this research, students in grades 9-12 engaged in design activities in an authentic school learning environment. Their understanding of the task interpretation was collected and evaluated through the survey questionnaire and students' design journals. This study is an innovative and potentially transformative study of learning experiences with the capacity to accelerate student learning of STEM content. Many studies suggest that metacognitive beliefs, decisions, and actions are important determinants of successful learning. Consequently, outcomes of this research will inform developers of instructional materials and curricula, as well as teachers planning classroom strategies and designers of engineering design initiatives.

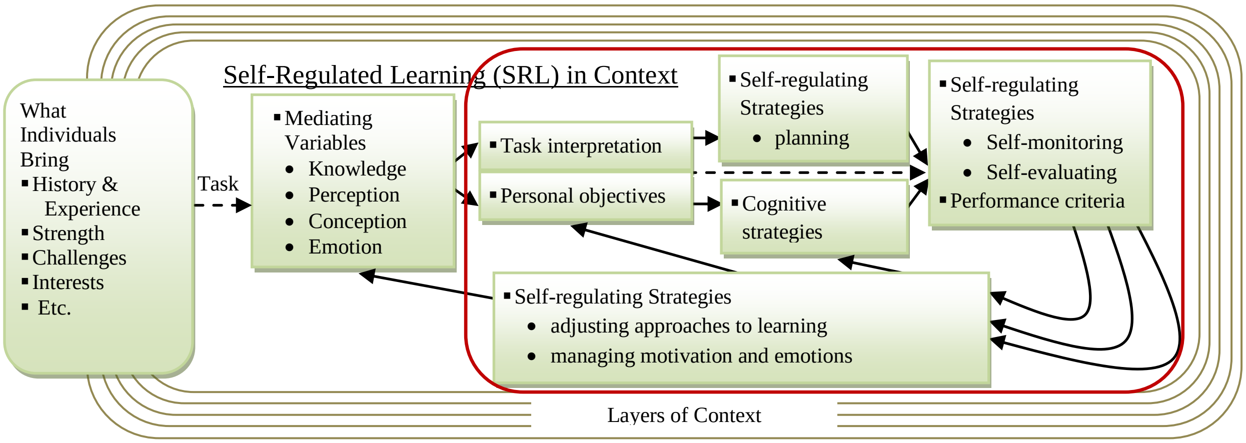
2. Relevant Literature

2. 1. Metacognition in Self-Regulated Learning Context

One of the hallmarks of psychological and educational theory and research on learning is the emphasis on helping students to become more knowledgeable of and responsible for their own cognition and thinking (Pintrich, 2002). The term used to describe this process is *metacognition*. The difference between cognition and metacognition is based upon functionality. While cognition concerns one's ability to build knowledge, process information, acquire knowledge, and solve problems, metacognition concerns the ability to control the working of cognition to ensure that the goals have been achieved or the problem has been solved (Flavell, 1979; Gourgey, 1998; Livingston, 1997). Metacognitive activity usually precedes and follows cognitive activity.

Informed by the classical theories of metacognitive knowledge and experience introduced by Flavell (1976), Pintrich (2002) divided metacognition into metacognitive knowledge and metacognitive control. Students hold metacognitive knowledge about strategies that might be used for a particular task and the conditions under which the strategies might be useful. Metacognitive control is a cognitive process that learners use to monitor, control, and regulate cognition and learning. Paris and Winograd maintained that the important issue in metacognition is to understand "the correspondence between metacognition and action. How do thoughts and feelings of learners guide their thinking, effort, and behavior?" (Paris & Winograd, 1990, p. 21). They observed two essential features of metacognition: (1) cognitive self-appraisal, which refers to learners' personal judgment about their ability to meet a cognitive goal; and (2) cognitive self management, which refers to learners' abilities to make necessary adjustments and revisions during their work. These two features are congruent with what are referred to as "what individuals bring" and "self-regulating strategies" in the Butler and Cartier's (Butler & Cartier, 2005; Butler & Cartier, 2004; Cartier & Butler, 2004) Self-Regulated Learning model.

The dynamic and iterative interplay between metacognitive and cognitive activity is described by Butler and Cartier (Butler & Cartier, 2005; Butler & Cartier, 2004; Cartier & Butler, 2004) in a SRL model, which characterizes SRL as a complex, dynamic, and situated learning process (Butler & Winne, 1995). This model involves central features that interact with each other: layers of context, what individuals bring, mediating variables, task interpretation and personal objectives, SRL processes, and cognitive strategies (see Figure 1). This study focuses primarily on student task interpretation, which is analogous to student task understanding, planning strategies, and cognitive strategies. Although the researcher emphasizes three SRL features, it is also important to understand how the students monitor their activities during design activity (see the SRL features in the red box). A student with good metacognitive skills and awareness uses these processes to oversee his or her own learning process, plan and monitor ongoing cognitive activities, and compare cognitive outcomes with internal or external standards (Flavell, 1979). Zimmerman and Pons (1986) found that consistency in employing self-regulated learning strategies is highly correlated with student achievement. Schoenfeld (1983) argued that an unsuccessful problem-solving effort may result from the absence of assessments and strategic decisions. Thus, students with poor metacognition may benefit from training to improve their metacognition and subsequent learning performance (Coutinho, 2008).



Source: Reproduced with permission from Butler, D. L., & Cartier S. C., "Multiple complementary methods for understanding self-regulated learning (SRL) as situated in context," 2005.

Figure 1. Self-Regulated Learning (SRL) in Context

2. 2. Task Interpretation, Planning Strategies, and Academic Performance

Previous studies revealed the influence and relevance of task interpretation in learning and problem solving in many areas (Pintrich, 2002; Georghiades, 2000; Lawanto, 2010; Butler, 1995; Lawanto & Johnson, 2009; Schraw, Brooks, & Crippen, 2005; Veenman, Elshout, & Meijer, 1997). Task interpretation is a key determinant of the goals students set while learning and the strategies they select to achieve those goals (Butler & Cartier, 2004; Butler & Winne, 1995).

Students with good task interpretation skills are likely to select effective planning activities (Flavell, 1979) which lead to better academic performance. Schoenfeld (1983) argued that an unsuccessful problem-solving effort may result from the absence of assessments and strategic decisions. Task interpretation is the heart of the SRL model insofar as it shapes key dynamic and recursive self-regulating processes. When confronted with academic work, students draw on information available in the environment, and on knowledge, concepts, and perceptions derived from prior learning experiences, to interpret the demands of a task (Butler & Cartier, 2004; Cartier & Butler, 2004; Butler, 1995). Task interpretation and personal objectives are expected to influence how students activate self-regulating and cognitive strategies during a design task.

Solving an engineering design problem is a structured and staged process. The manner in which students use strategy, look at what happened, and search alternative solutions reflects how metacognition is applied in design. Students solve a design problem by following the design phases. Dym and Little (2009) proposed that the design process consists of five main phases: problem definition, conceptual design, preliminary design, detailed design, and design communication (Table 2). This study used Dym and Little's five-stage prescriptive model to categorize and code engineering design strategies and to evaluate students' metacognitive activities during the five design phases.

Table 2. A five-stage prescriptive model of the design process

Problem Definition	Preliminary Design
Co – Clarify objectives	Ma – Model and analyze chosen design
Emo – Establish metrics for objectives	Te – Test and evaluate chosen design
Ic – Identify constraints	
Rp – Revise client's problem statement	
Conceptual Design	**Detailed Design**
Ef – Establish functions	Rod – Refine and optimize chosen design
Er – Establish requirements	Afd – Assign and fix design details
Emf – Establish means for functions	**Design Communication**
Ga – Generate design alternatives	Dfd – Document final design
Ram – Refine and apply metrics to design alternatives	
Cd – Choose a design	

3. The Study

3.1 Research Design

A central goal of this research is to describe the task interpretation of students engaged in a design activity and determine the extent to which students translate their understanding of their design task to their planning and cognitive strategies. As suggested by MacLeod and his colleagues (MacLeod, Butler, & Syer, 1996), a mixed methods approach was used to address the research question because it would "build on the synergy and strength that exists between quantitative and qualitative research methods to understand a phenomenon more fully than is possible using either quantitative or qualitative methods alone" (Gay, Mills, Airasian, 2009, p. 462).

3.2 Study Participants

Twenty-nine students at one Colorado high school participated in this study. The subjects for this project were students enrolled in classes in Architectural Design and Robotics Design. Students worked individually in the Architectural Design class, but worked in teams in the Robotics Design class. The requirements of the design projects were specified by the teacher of those classes. Descriptions of these two courses can be found below.

<u>1. Robotics Design</u>

Students are required to work in a team of two or three to design and build a robot capable of operating under a tele-operated mode to navigate inside a 4' x 8' table with 2"-high walls populated with 12 balls (two colors). Emphasis is on the creation of a robotics team to represent the high school at local, regional, and national events such as the FIRST Robotics Competition.

<u>2. Architectural Design</u>

Students with drafting/CAD knowledge focus on residential design and construction. They are introduced to multiple facets of construction and are required to design a residential structure. Upon completion of the course, students will have produced a set of plans that could be used to build the house.

3.3 Instrumentation

Three subsections of the Engineering Design Questionnaire (EDQ) were developed to capture SRL features during the design activity. EDQ subsections 1, 2, and 3 are used at the early, middle, and final stages of engineering design activity, respectively. Measurement scales on the EDQ range from 1 to 4 (i.e., 1 = *never*, 2 = *sometimes*, 3 = *often*, and 4 = *always*). The EDQ was first developed and tested in spring 2010. Freshman engineering students at USU tested this questionnaire. Since this study involved secondary students, some rewording was required in the Inquiry Learning Questionnaire developed by Butler and Cartier based on their theoretical model (Butler & Cartier, 2005; Butler & Cartier, 2004; Cartier & Butler, 2004; Butler & Cartier, 2003). The ILQ was developed, pilot-tested, validated, and used in previous research to capture the relationships between and among the main features (e.g., task interpretation, personal goals, planning strategies, and cognitive strategies) of the SRL model (see Figure 1) for postsecondary students engaged in inquiry learning in first-year Biology.

3.4 Data Collection Procedures

In this study, a survey questionnaire and journal writing were used to capture students' metacognition. This study used EDQ as survey questionnaire and Web-based Engineering Design Notebook (WEDN) for journal writing (see Figure 2). WEDN is the Engineering and Technology Education Department's online system implemented using Moodle learning management system. Students' perceptions about task interpretation, personal objectives, planning strategies, cognitive strategies, and self-regulating strategies have been collected through EDQ. Except for personal objectives, data from these metacognitive variables also have been collected through WEDN.

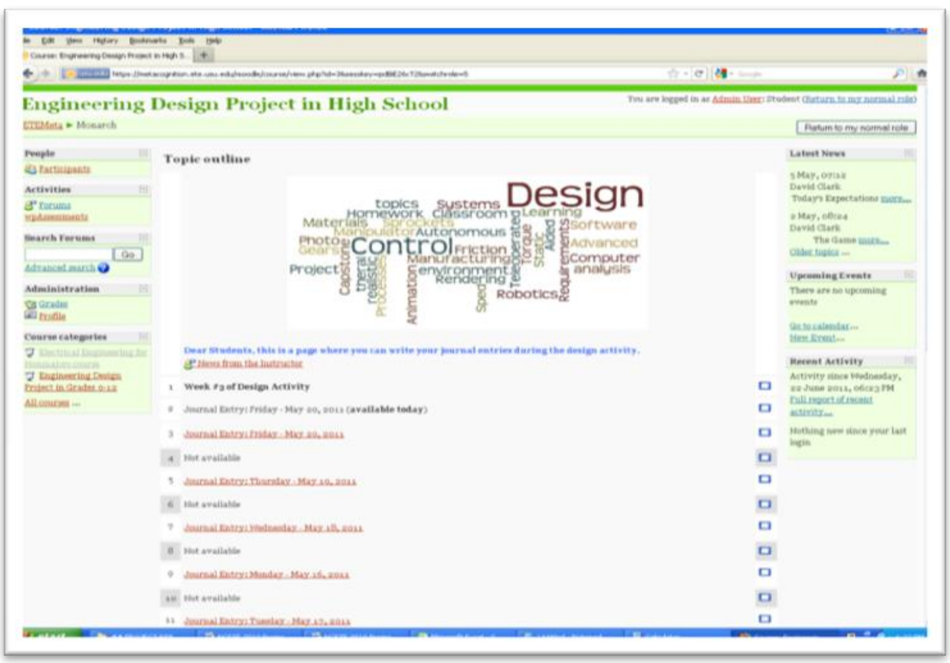


Figure 2. Web-based Engineering Design Notebook

In this study, data were collected from the EDQ on the early and middle phases of the design project. While the early subsection of EDQ assessed students' understanding of task and planning strategies, the middle subsection of EDQ assessed their cognitive strategies, and self-regulated strategies (i.e., monitoring strategies). Study participants were asked to write their design journal through the WEDN whenever they make progress through the design task. Although WEDN entries are considered self-report data, they are more specifically localized in reports written by students.

Each student was provided an individual account to access WEDN. Since the WEDN was new to the students, the researcher decided to allow one week for the students to test the WEDN. The teacher of the classes took a role in facilitating the students to test the WEDN. The Institutional Review Boards of the high school and USU approved the data collection protocol before data collection began.

Figure 3a & 3b. Activity and Design Artifact Example in Architectural Design class

Figure 4a & 4b. Activity and Design Artifact Example in Robotics Design class

3.5 Data Analysis

Quantitative and qualitative data from multiple sources that do not share the same source of error (Ericsson & Simon, 1980; Garner, 1988) and a triangulation technique were used to validate the data and answer the research questions. Data collected from the EDQ were evaluated qualitatively using a graphical view in three ways. *First*, the questionnaire items were clustered based on SRL features and the mean scores of all SRL items for each feature were calculated. *Second*, the mean scores on each item from the same design phase (i.e., problem definition, conceptual design, preliminary design, detailed design, and design communication) were compared across SRL features (e.g., task interpretation, planning strategies, and cognitive strategies). *Third*, the transitions of each questionnaire item across SRL variables were evaluated in a graphical view.

Students' design journals recorded in the WEDN pages were coded to identify students' task interpretation, planning activities and engineering design strategies. Students' WEDN were also scored using a rubric that captures students' metacognitive skills (similar to the work of Butler (1998)), such as perceptions of typical task requirement, planning strategies, the degree to which described strategies are focused, personalized, and connected to task demands, and students' descriptions of how they reflect on progress and manage design activities accordingly.

4. The Findings

The findings are presented to answer one research question: *To what degree do students' understandings of the design task reflect on their working plans and selected cognitive strategies*?

4.1. Study Participant Demographics Profile

Twenty-nine students participated in this study. Seven students (5 females and 2 males) were in the Architectural Design class and 22 students (3 females and 19 males) were in the Robotics Design class. Twenty of the participants (69%) identified themselves as Caucasian, with the next highest demographic being Asian-Pacific Islander with five students (17%). The Grade Point Average (GPA) was almost normally distributed around the mid-3 range. Most participants were freshman in high school (52%), followed by sophomore (38%), then senior (7%), and junior (3%). Fifty-two percent of the students claim to be considering engineering or technology schooling, whereas 48% claim to not be interested. The complete list of demographics information of the study participants is shown in Table 1-5.

Table 1. Gender

#	Answer	Response	%
1	Male	21	72%
2	Female	8	28%
	Total	29	100%

Table 2. Ethnicity

#	Answer	Response	%
1	African American	1	3.5%
2	Asian-Pacific Islander	5	17%
3	Caucasian	20	69%
4	Hispanic	2	7%
5	Native American	0	0%
6	Other	1	3.5%
	Total	29	100%

Table 3. GPA

#	Answer	Response	%
1	< 2.00	0	0%
2	2.00 - 2.49	2	7%
3	2.50-2.99	7	24%
4	3.00-3.49	5	17%
5	3.50-3.99	9	31%
6	4.00-4.49	6	21%
7	4.50-5.00	0	0%
	Total	29	100%

Table 4. Class Level

#	Answer	Response	%
1	Freshman	15	52%
2	Sophomore	11	38%
3	Junior	1	3%
4	Senior	2	7%
	Total	29	100%

Table 5. Considering Engineering/Technology School

#	Answer	Response	%
1	Yes	15	52%
2	No	14	48%
	Total	29	100%

4. 2. Mediating Variables and Personal Objectives

Each student has different mediating variables and personal objectives when dealing with the design activity. Mediating variables refer to their perceptions about the task and prior knowledge related to the task. When starting the design task, 48% of the participants claimed to have a decent grasp on the background knowledge regarding the design task that they were about to solve, 31% claimed to have a small amount of knowledge regarding the background of the design task, and 21% claimed to have a lot of background knowledge. No student reported a complete lack of background knowledge related to the task. When asked to rate the complexity of the design task, the majority (18 participants, 62%) thought the design task was pretty complex. In contrast, no participant thought the task was without complexity. Regarding their confidence in completing the design task, students were enthusiastic, with 55% claiming "very much" confidence, 38% claiming "somewhat" confidence, only 3.5% claiming no confidence, and 3.5% claiming confusion. In addition, students' personal objectives influence the accomplishment of the design task. "Getting good marks" is the highest ranked personal objective (M = 3.38) on the 1-never, 2-sometimes, 3-often, 4-always scale. The next highest rank was "to do a good job on the task" with M = 3.27, followed by "learning more" with M = 2.67. The least common objectives were "do as little work as possible" and "finish as quickly as possible" (see Tables 6-9 below).

Table 6. Level of background knowledge regarding the design task

#	Answer	Response	%
1	Nothing	0	0%
2	A small amount	9	31%
3	Pretty much	14	48%
4	A lot	6	21%
5	I don't know	0	0%
	Total	29	100%

Table 7. Students' responses regarding the complexity of the design task

#	Answer	Response	%
1	Not at all complex	0	0%
2	A little bit complex	10	34%
3	Pretty complex	18	62%
4	Very complex	1	4%
5	I don't know	0	0%
	Total	29	100%

Table 8. Students' perceptions about confidence to complete the design task

#	Answer	Response	%
1	Not at all	1	3.5%
2	A little bit	0	0%
3	Some what	11	38%
4	Very much	16	55%
5	I don't know	1	3.5%
	Total	29	100%

Table 9. Students' personal objectives in completing the design task

#	Question	Never	Sometimes	Often	Always	Responses	Mean
1	finish as quickly as possible	8	15	4	2	29	2.00
2	work with my friends	3	10	10	6	29	2.65
3	do a good job on my design task	0	5	11	13	29	3.27
4	learn more about the topic of the design task	0	11	14	4	29	2.76
5	learn more about how to conduct a design task	1	8	18	2	29	2.72
6	do as little work as possible	17	9	1	2	29	1.59
7	please or impress other people	9	10	5	5	29	2.21
8	get good marks	0	4	10	15	29	3.38

4. 3. Design Activities
This study used Dym and Little's (2009) five-stage prescriptive model to categorize and code cognitive engineering design strategies and evaluate students' metacognitive activities during the five design phases: problem definition, conceptual design, preliminary design, detailed design, and design communication. The findings about design activities are organized into four main parts of SRL features: task interpretation, planning strategies, cognitive strategies, and monitoring and fix up strategies (see Figure 5 below).

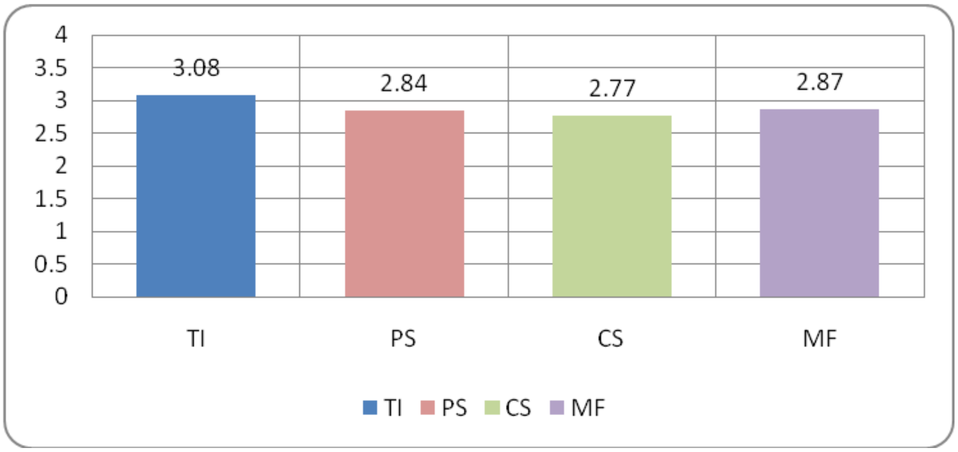


Figure 5. Mean Scores Distribution of SRL Features

In general, the findings show that students have good understanding about the task interpretation, but they might find difficulty to carry out their understanding to make design plans. In addition, lack of planning strategies influenced their awareness of cognitive strategies. However, they were almost often monitoring their design progress and made some actions to encounter any problems.

4. 3. 1. Survey Analysis: Description of SRL Features across Dym and Little's Design Phases

4.3.1.1 Description of Task Interpretation across Design Phases
According to the mean scores of the Dym and Little's design phases, the students scored an average of 2.92 (*SD* = .26) for task interpretation. During the design process, on average students have high scores in problem definition, conceptual design, and preliminary design; the means are higher than 3. However, when they were moving to detailed design and design communication phases, the students have lower scores. This average value says that the students almost often thinking and doing what they ought to do to solve the design task.

Students often knew what they ought to do to understand the design problem, to generate concepts or schemes of design alternatives or possible acceptable design, and to develop a model that reflects the actual final design. However, the students sometimes knew what they ought to do to refine the chosen design and to communicate design processes and outcomes (see Figure 6 below).

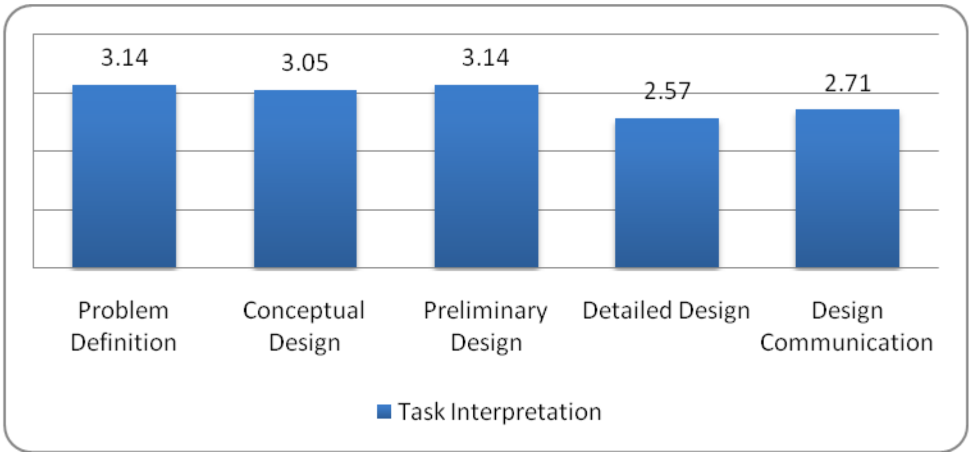


Figure 6. Task Interpretation across Design Phases

4. 3.1.2. Description of Planning Strategies across Design Phases
Compared to students' average score for their understanding of task demand, the average score for their planning strategies was relatively low. According to the mean scores of the design phases, the students scored an average of 2.89 (*SD* = .15). Specifically, the scores of problem definition, conceptual design, and preliminary design are categorically lower; the students, on average, had medium scores (below 3). As they transitioned to detailed design and design communication, they had scores above 3, on average. Students sometimes made relevant plans to understand the design problem, to generate concepts or schemes of alternatives or possible acceptable design, and to develop a model that reflects the actual final design. The students often made relevant plans to refine the chosen design and to communicate the design process and outcomes (see Figure 7 below).

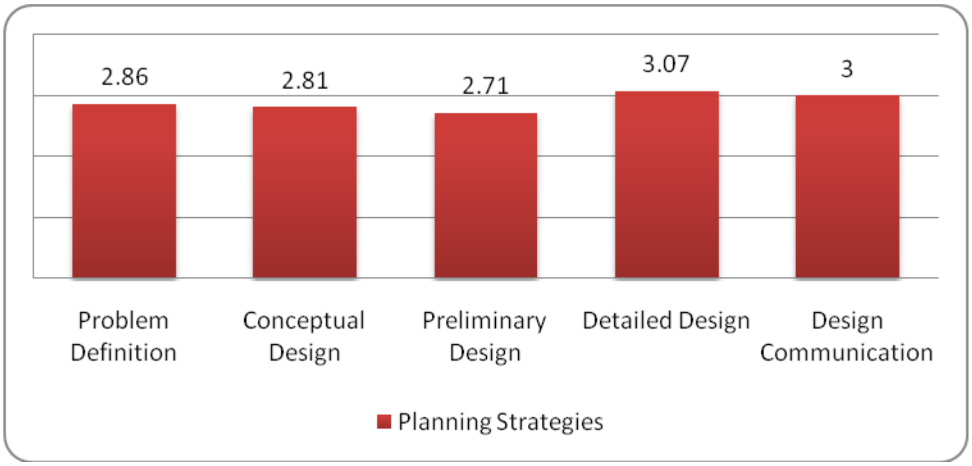


Figure 7. Planning Strategies across Design Phases

4. 3.1.3. Description of Cognitive Strategies across Design Phases
According to the mean scores of the five design phases, the students scored an average of 3.09 (*SD* = .17) for cognitive strategies. In this phase, students, on average, had medium scores on the problem definition, with high scores as they transitioned to conceptual design, preliminary

design, detailed design, and design communication. The students peaked with preliminary design with the highest score. The students often chose relevant strategies to generate concepts or schemes of design alternatives or possible acceptable design, to develop a model that reflects the actual final design, to refine the chosen design, and to communicate design process and outcomes. The students sometimes chose relevant strategies to understand the design problem (see Figure 8 below).

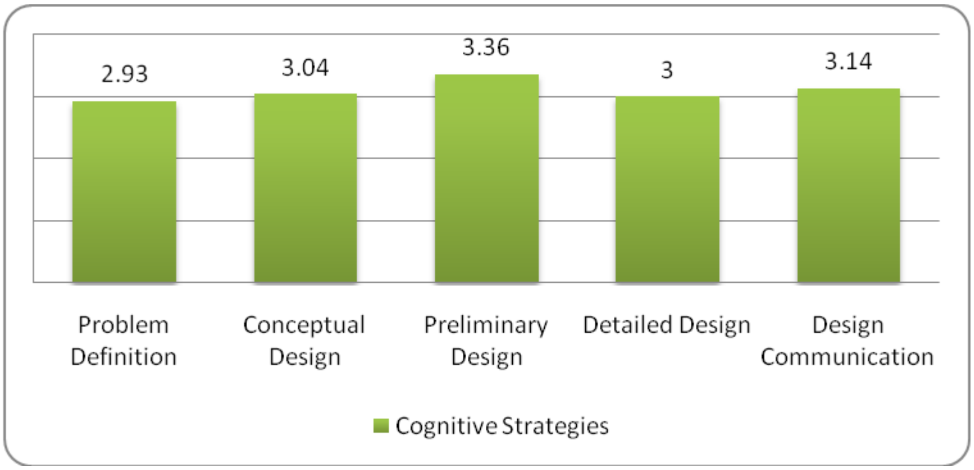


Figure 8. Cognitive Strategies across Design Phases

4. 3.1.4. Monitoring and Fix Up Strategies

The students scored an average of 3.22 (*SD* = .08) for monitoring and fix up strategies according to the mean scores of the five design phases. During this phase, students, on average, had high scores through all phases. The lowest was conceptual design and the highest was problem definition. Students often monitored and made relevant adjustments to understand the design problem, to generate concepts or schemes of design alternatives or possible acceptable design, to develop a model that reflect the actual final design, to refine the chosen design, and to communicate design process and outcomes (see Figure 9 below).

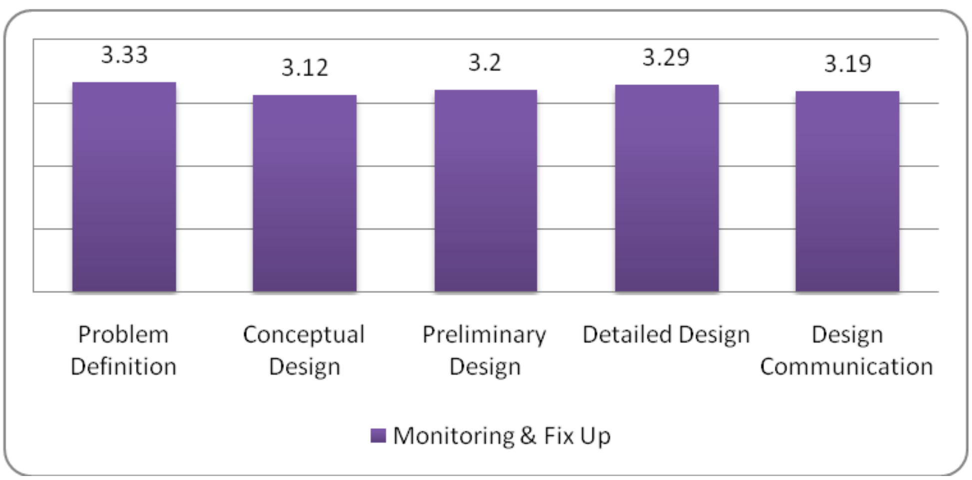


Figure 9. Monitoring and Fix Up across Design Phases

It is also interesting to note how the mean scores of SRL features fluctuate across Dym and Little's design phases. Figure 10 shows how task interpretation was decreasing. It looks stable from problem definition to conceptual design and preliminary design, but starts decreasing at detailed design. Design communication scores the lowest in task interpretation. Planning strategies are increasing across the phases, but decreasing in design communication. Cognitive strategies have similar description with planning strategies, specifically their average scores of detailed design are the highest among the five phases. In addition, monitoring and fix up strategies have slightly similar average scores across the five phases; except for the score of problem definition, it has the highest score.

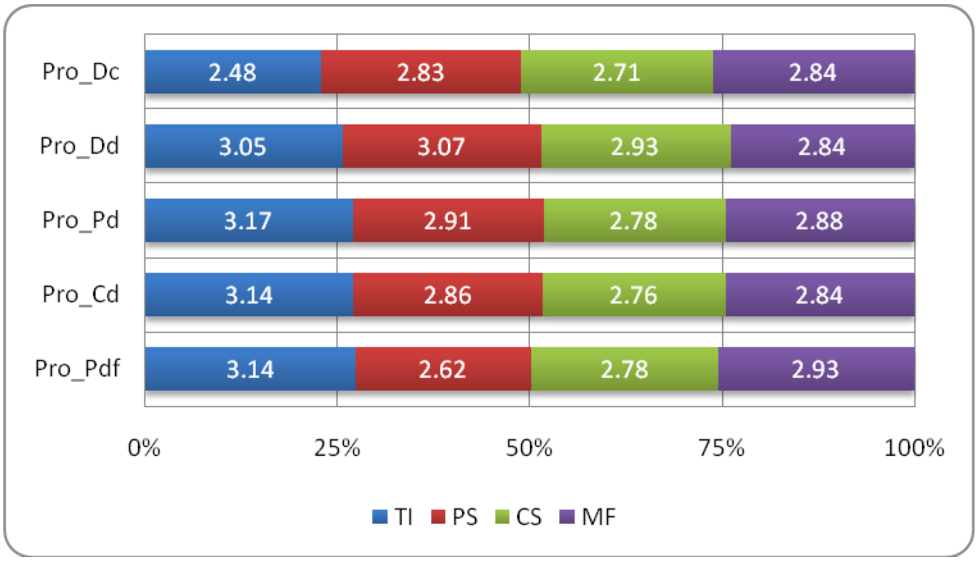


Figure 10. Dym and Little's Design Phases across SRL Features

4.3.2. Survey Analysis: Description of Design Phases across SRL Features

The researcher also used different perspective to describe how students' task interpretation is reflected in planning, cognitive, and monitoring & fix up strategies. The following subsections of this report show how the dynamicity of SRL features described in each design phase: problem definition (Pro_Pdf), conceptual design (Pro_Cd), preliminary design (Pro_Pd), detailed design (Pro_Dd), and design communication (Pro_Dc).

4.3.2.1 Description of Problem Definition across SRL Features

From the data collected at the early stage of the design project, in this case problem definition phase, it is apparent that the students scored very high (M = 3.14) on task interpretation aspect; they were highly aware of what they were required to do to solve the design problem. Despite their high awareness on task interpretation, the students did not seem to be aware of the planning strategies (M = 2.62). This condition also influence their cognitive strategies, they way they executed their planning strategies (M = 2.78). However, they often monitored and fixed up any challenges and problems (M = 2.93).

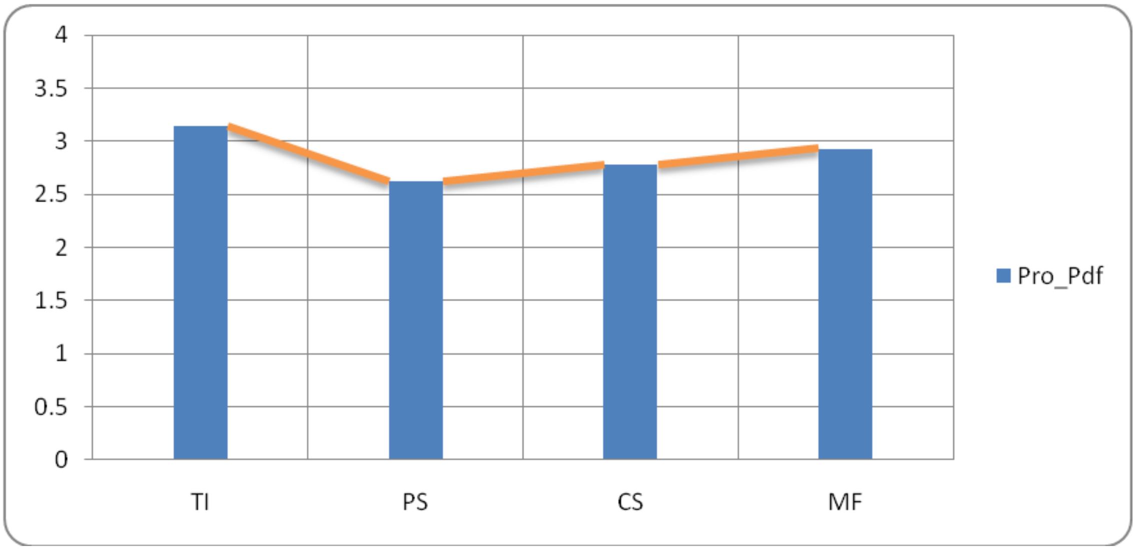


Figure 11. Problem Definition across SRL Features

4.3.2.2 Description of Conceptual Design across SRL Features

Figure 12 shows that in the conceptual design phase, students scored very well in task interpretation (*M* = 3.14), while scoring a 2.86 in planning strategies. Despite understanding the task interpretation and moderately understanding their planning strategies, students scored lowest in cognitive strategies with a 2.76. Showing an increased amount of knowledge, the students scored a 2.8 in monitoring and fix-up.

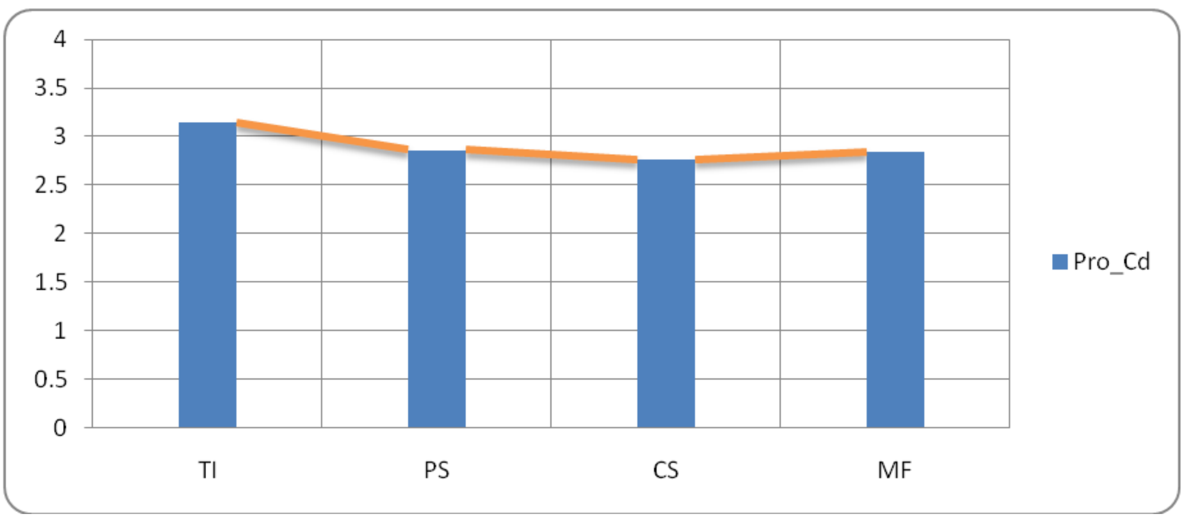


Figure 12. Conceptual Design across SRL Features

4.3.2.3 Description of SRL Features in Preliminary Design

In the preliminary design phase, students showed high understanding in task interpretation with a 3.17, dropping to a 2.91 in planning strategies. Dropping further, the students showed a 2.78 in cognitive strategies, demonstrating a lack of strategy selection despite their strong task interpretation. For monitoring and fix-up, the students showed improvement with a score of 2.88.

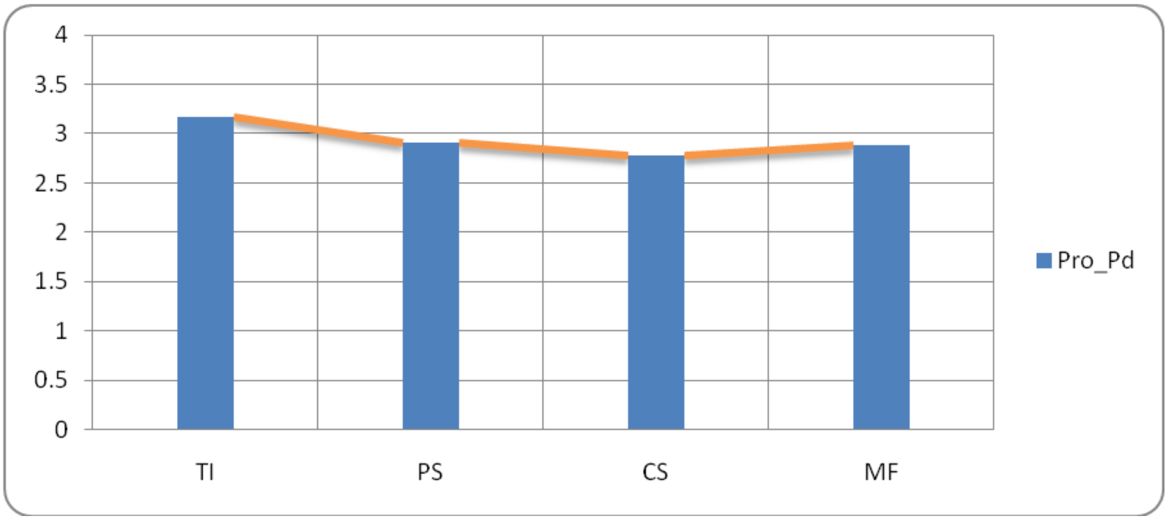


Figure 13. Preliminary Design across SRL Features

4.3.2.4 Description of SRL Features in Detailed Design

In the detailed design phase, students demonstrated a moderately high score in task interpretation, and a very high score in planning strategies with a 3.05 and a 3.07, respectively. These numbers drop to a 2.93 in cognitive strategies, dropping further to 2.84 in monitoring and fix-up.

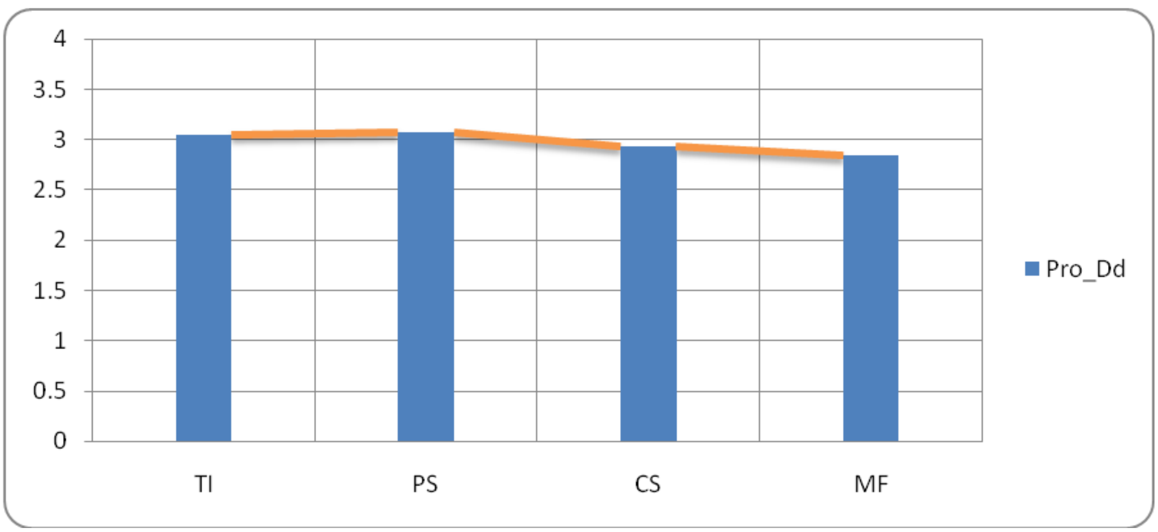


Figure 14. Detailed Design across SRL Features

4.3.2.5 Description of SRL Features in Design Communication

In the design communication phase, the students scored a low 2.48 in task interpretation, showing a lack of understanding of the task. This score rises in the planning strategies to 2.83, showing a higher understanding, then drops to 2.71 in cognitive strategies. Monitoring and fix-up strategies have a higher score, 2.84 compared to cognitive strategies.

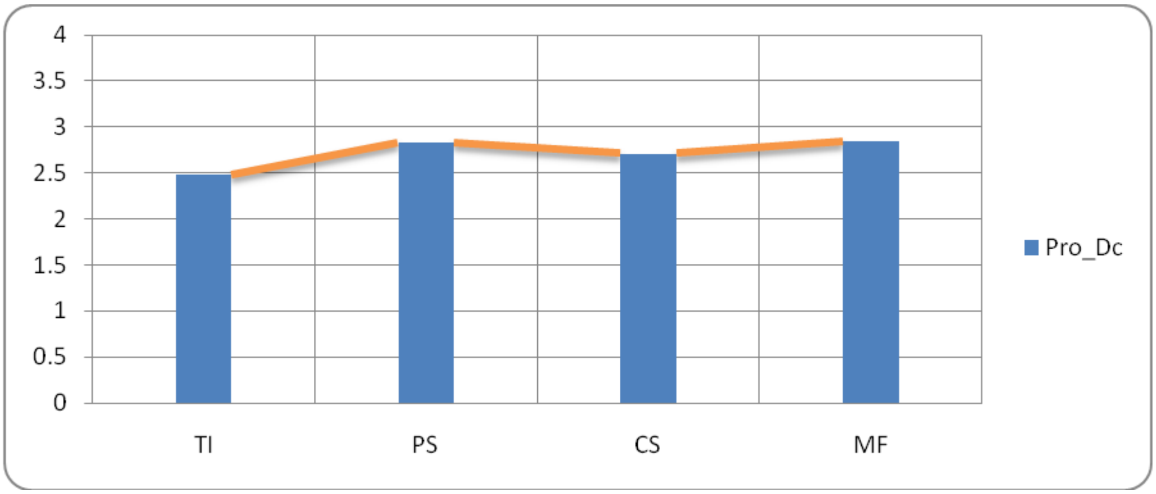


Figure 15. Design Communication across SRL Features

4.3.3 Journal Writing Analysis

Student preparation of the engineering design journals was guided by four different prompts for each entry. First, they were asked to describe their present understanding of the design task. Second, they were required to describe accomplishments during the day they wrote the journal. Following the accomplishments, they were asked to identify and describe any struggles and areas where improvements were needed. Students were also asked to describe their plans to continue their project and their strategies to carry out their plans. Examples of students' journal writing regarding project progression can be read in Table 10 below.

Table 10. Examples of Journal Entries in Different Week

Question 1 (present understanding)	Question 2 (accomplishments & challenges)	Question 3 (planning)	Question 4 (strategies)
Example of Student X's Journal Writing in Week #1			
The current design task is to design and model a library. This library has specifications such as it is on a 125' by 125' lot, it must reflect the town's mining history and it must accommodate a town of 25,000.	Today I started thinking about what different rooms should be in a library and where they should be. I was just starting to think about the design task and how to use my time.	My next step is to draw out a floor plan on graph paper and decide things such as how many floors I need, and where to place rooms. I then will figure out the dimensions of the different rooms.	My strategy is to spend this first week using graph paper to sketch out ideas and dimensions for my library. I need to figure out all of the spacing and dimensions before putting it in the computer program.
Example of Student X's Journal Writing in Week #2			
The design task is to continue to put our drawing of a library into ArchiCAD and then to model and build it. This building has to meet certain specifications that were previously determined.	Today I finished adding all of the windows and doors to the first and second floors. I also added some lighting and furniture on the first floor.	The next step in continuing the project is to work more on the layout book and electrical key because that is also part of the assignment. Also, I need to change some of the settings on the walls and doors so that they are all the same.	My strategy to carry out my plans is to continue working hard and working on the most important stuff first, like the layout book and electrical key. Also, I need to try and stay on schedule so that I don't get behind.

Table 10. Examples of Journal Entries in Different Week

Question 1 (present understanding)	Question 2 (accomplishments & challenges)	Question 3 (planning)	Question 4 (strategies)
Example of Student X's Journal Writing in Week #3			
The design task is to create, design and build a library. This library must meet certain specifications about its size, capacity, and what rooms it needs.	My accomplishments today were that I added and completed the footing, roof and some of the electrical pieces. I also cut a hole in the slab for where the stairs are.	My plans to continue are doing the documentation and schedules and the build my model out of cardboard.	My strategy to carry out my plans is to work hard so that I can finish most of the model in class.

The teacher gave a score for each answer to the four questions. Similar to the work of Butler (1998), the scores used for journal scoring ranged from 0 to 3; a highest score represents a clear and specific answer. The examples of journal writing scored 3 and 1 for task interpretation are presented below:

> *Scored 3 for Student A*:
> "My understanding of the task is that we need to build a library that has an architectural influence of the towns mining history. The library also needs to have meeting rooms, performance space, computer access area, outside area, and office rooms. It must fit in a square corner lot that is 150 ft x 125 ft and be set back 6 ft from the property line. My design should also include basic necessities such as bathrooms and handicap access."

> *Scored 1 for Student B*:
> "I understand that I have to build a library for a small town of 25,000. The building of this library shouldn't take too long. I just need to concentrate and focus."

Although the students were not required to write in their design journals every day, they made journal entries whenever they were making progress. Twenty-eight out of 29 students wrote their journal entries; only one student did not write any design journal. Results show that the mean scores of SRL features confirm the results of survey questionnaire. Specifically, the score of task interpretation is the highest compared to other SRL features (M = 1.4). In contrast, the students had a lowest mean score for planning strategies (M = 1.1). In addition, cognitive and monitoring strategies have the same score (M = 1.3).

4.3.4 SRL Features Comparison between Architecture and Robotics Projects

As mentioned before, the participants worked on two different projects: Architectural and Robotics design projects. According to Butler and Cartier's SRL model, engineering design tasks are examples of the contexts. It is interesting to understand the differences of SRL features in those two engineering design projects. Between the Architecture and Robotics groups, there were many differences. The Architecture group scored a 2.99 on task interpretation, while Robotics group had a higher score of 3.11. In every other category, Architecture had a higher score than Robotics. In planning strategies, the scores were roughly equal, with Architecture scoring a 2.86 while Robotics scored a 2.84. In cognitive strategies, Architecture had a 3.06 and Robotics had a 2.68. Architecture had a strong monitoring and fix-up score of 3.20, leaving Robotics behind with a 2.76.

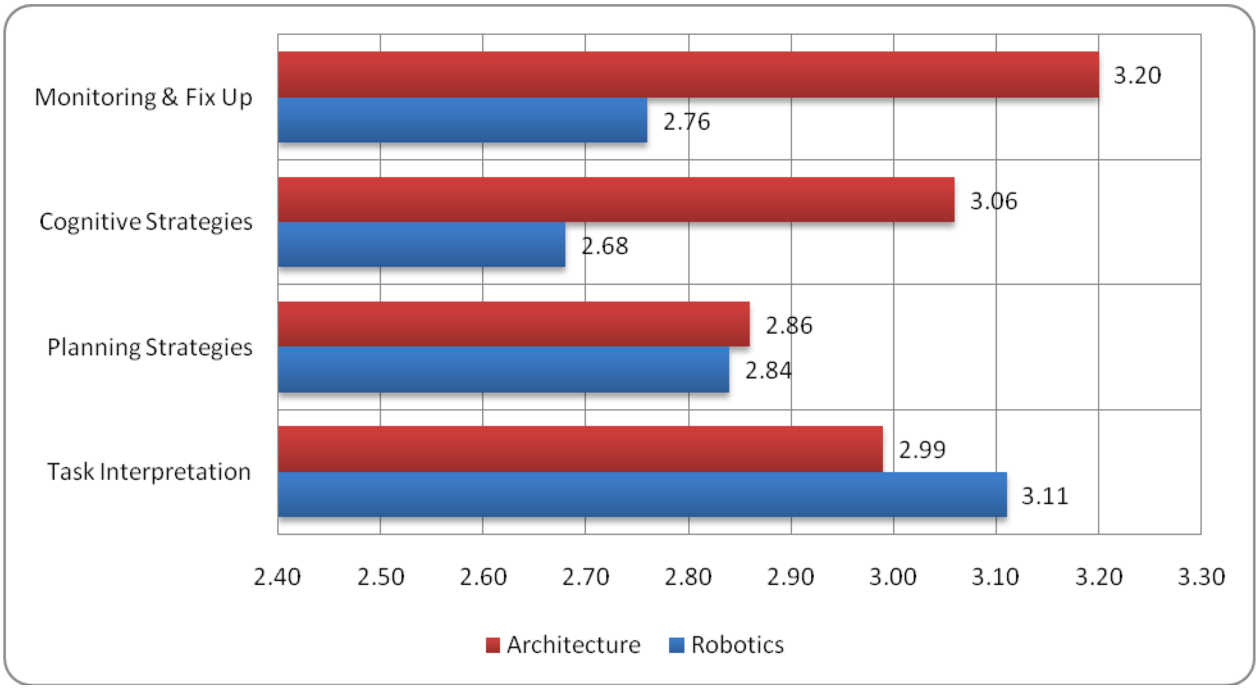


Figure 16. SRL Features Comparison between Architecture and Robotics Projects

5. Discussion and Future Study

The results of this study provide clear understanding how high school students deal with engineering design activity from self-regulated learning perspectives. From the analysis, the findings suggest that levels of understanding of the tasks were high in problem definition, conceptual design, and preliminary design. In contrast, students were found to be lacking on those three design process components in the area of planning strategies. Students performed high in cognitive strategies except for problem definition.

Data analysis from survey questionnaires and journals revealed a similar result: students had the highest score in task interpretation compared to other SRL features. Students had very high awareness of the task demands. This finding is consistent with a study conducted by Atman, Kilgore, and McKenna (2008). In their study, “Understanding the Problem” is the most important design activity, not only for first- and fourth-year students, but also for experts. In addition, there was a lack of ability to transform task interpretation to planning strategies. Based upon the findings, the researcher assumes that at least two factors influenced the way students approached the design task. First, most participants were freshmen and sophomores in high school. Second, when asked to rate the complexity of the design task, the majority thought the design task was pretty complex. No participant thought the task lacked complexity. These facts show that the students had lack of experiences to engage in design projects.

Future research endeavors will emerge from this work, as efforts to improve high school students’ understanding of engineering are coupled with a body of literature focused on uncovering the elusive cognitive thought processes employed by students as they practice engineering design activities. These purposes are congruent with National Center for Engineering and Technology Education (NCETE) mission which is to build capacity in technology education and to improve the understanding of learning and teaching of high school students and teachers as they apply engineering design processes to technological problems (NCETE, 2000).

As an exploratory study, this study will lead to further research to investigate metacognitive practices used by students during engineering design activities. Future studies will not only help build the body of knowledge on metacognition used in technology/ engineering related design activities, but will also help us understand how metacognition matures over time (from secondary to post-secondary education levels). In addition, the researcher plans to involve a larger number of participants in order to minimize the effects of attrition and to provide a sample that is more representative of the overall population. Since only a limited number of studies have investigated the effects of gender in engineering design at high school level exist, the researcher is also interested in designing research to investigate gender influences upon metacognition in engineering design.

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