AC 2011-919: TASK INTERPRETATION AND SELF-REGULATING STRATEGIES IN ENGINEERING DESIGN PROJECT: AN EXPLORATORY STUDY

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Task Interpretation and Self-Regulating Strategies in Engineering Design Project: An exploratory study

Abstract

Design tasks are ubiquitous, complex, ill-structured, and challenging to students and professional engineering designers. Successful designing depends on having not only adequate knowledge but also sufficient awareness and control of that knowledge, known as metacognition. Research suggests that metacognition not only enhances learning outcomes but also encourages students to be self-regulated learners who are metacognitively, motivationally, and behaviorally active participants in their learning process.

This article evaluates the extent to which students' task interpretation of the design project is reflected in their working plans and monitoring/regulating strategies. Butler and Cartier's Self-Regulated Learning (SRL) model was used to evaluate the dynamic and iterative interplay between metacognitive and cognitive activity. SRL dimensions such as design process, task management, task value, and criteria of success were evaluated. Twelve freshman engineering students at Utah State University participated in the study while they engaged in an engineering design project for a mechanical engineering course, "Engineering Graphics." Students were asked to complete the Engineering Design Questionnaire (EDQ) at the early, middle, and final stages of the project.

Data collected were evaluated quantitatively and qualitatively using graphical views. In addition, the mean value of each item from the same SRL dimension was compared across SRL episodes (i.e., task interpretation, planning strategies, cognitive strategies, monitoring and fix-up strategies, and criteria). From the analysis, the findings suggest that the level of understanding of the task was clearly reflected in students' plans with particular emphasis on getting a good overview of the design task at the early stage of the project. Students were found to be lacking in the areas of planning the methods used and anticipating the time required to solve the design task at the early stage of the project. Overall, students excelled in monitoring and regulating the design process and task management, although lower scores were found on several activities, such as seeking alternative approaches to investigating the problem, design solution, time planning, and the effective use of resources and materials during the project. When regarding their criteria of success, students considered task management issues to be more important than issues relating to the design process.

Keywords: Metacognition, Engineering Design, Self-Regulated Learning.

1. Introduction

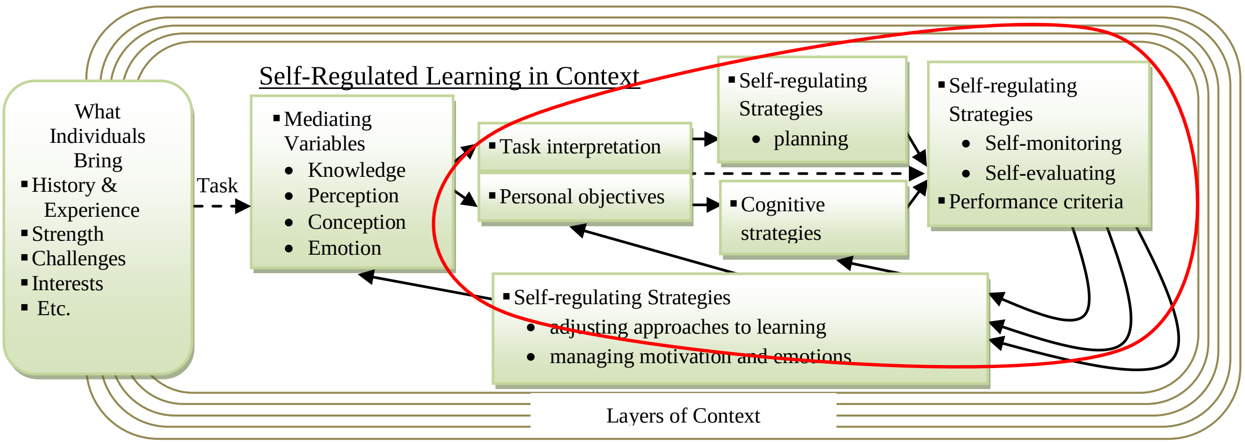
The concepts of metacognition and learning have been studied extensively, especially in the areas of writing[1], mathematics[2], and study strategies as a function of testing[3]. While there is a growing interest in metacognitive research and the vital function of metacognition in problem-solving, few studies have comprehensively evaluated it in the context of engineering design activities.

Design is recognized as the critical element of engineering thinking, which differentiates engineering from other problem-solving approaches[4]. Metacognitive skills are essential in solving design problems because they "help students become active participants"[5, p. 18] in solving problems that involve ambiguous specification of goals, no predetermined solution path, and often require the integration of multiple knowledge domains[6, 7]. 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[8]. A recently completed STEM Talent Expansion Program (STEP) project[9], which implemented a number of projects in first-year engineering courses at Texas A&M University (TAMU), found a lack of student abilities to manage learning and problem-solving. It is clear that there is vital need to help students improve their metacognitive skills through metacognitive training.

2. Metacognition and Self-Regulated Learning

In a simple definition, metacognition refers to one's state of awareness of one's thinking[10]. Flavell, regarded as a foundation researcher in metacognition, divided it into two aspects: *metacognitive knowledge* and *metacognitive experiences* or *strategies*. He described metacognitive knowledge as "knowledge concerning one's own cognitive processes and products or anything related to them"[11, p. 232]. It can lead someone to engage in or abandon a particular cognitive enterprise based on its relationship to his or her interests, abilities, and goals. Flavell further classified metacognitive knowledge into three categories: knowledge of person, task, and strategy. Metacognitive experiences help to regulate and oversee learning, and consist of planning and monitoring cognitive activities, as well as checking the outcomes of those activities. While cognition entails 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[8, 12, 13]. For that function, metacognitive activity usually precedes and follows cognitive activity.

The dynamic and iterative interplay between metacognitive and cognitive activity was described by Butler and Cartier[14, 15, 16] in a self-regulated learning (SRL) model, which characterizes SRL as a complex, dynamic, and situated learning process[17]. This model involves six 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* (Figure 1). These features are called SRL episodes; sequence processes that might capture students' activities in completing engineering design project. Students' activities across SRL episodes are clustered into two dimensions or categories of activities: design process and task management.



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

Figure 1. Self-Regulated Learning in Context

First, layers of context may include the learning environments such as school, classroom, teachers, instructional approaches, curricula, and learning activities (e.g., reading, writing, and problem-solving). Recognizing the ways in which multiple interlocking contexts shape and constrain the quality of student engagement in learning is essential for understanding SRL.

The second feature involves what individuals bring to the context, which includes factors such as student strengths, challenges, interests, and preferences. Over time, students accumulate a learning history that shapes their development of knowledge and skills, self-perceptions, attitudes toward school, and concepts about academic work[15, 16, 18]. Third, students' SRL is mediated by knowledge, perceptions about their competence and control over learning, and perceptions about activities and tasks. These mediating variables also include emotions experienced before, during, and after completing a task.

The fourth feature is student task interpretation and personal objectives. Task interpretation (or task demand) 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[15, 16, 19]. Students' interpretation of task demands is a key determinant of the goals set while learning, the strategies selected to achieve those goals, and the criteria used to self-assess and evaluate outcomes[15, 16, 17]. Students set personal objectives such as achieving task expectations that impact their direction for engaging or not engaging in learning. Task value, which is part of students' personal objectives, refers to a student's perception of the extent to which the task is interesting, important, and useful. Task value is an effective predictor of academic outcomes[20, 21].

In light of their interpretations of task and personal objectives, students manage their engagement in academic work by using a variety of self-regulating strategies: planning, monitoring, evaluating, adjusting approaches to learning (i.e., cognitive strategies), and managing motivation and emotions. Students plan how to use available resources, select strategies for task completion, self-monitor progress, and adjust goals, plans, or strategies based upon self-perceptions of progress or feedback and performance. These strategies are iterative and dynamic endeavors.

Because students engage in such ubiquitous, complex and ill-structured problem-solving, these SRL features dynamically interact and influence how students solve a design task. The focus of this article is to evaluate the extent to which students' task interpretation of the design project is reflected in their working plans and selected cognitive and monitoring/adjusting strategies (see the red box in Figure 1).

Solving an engineering design problem is a structured and staged process. The ways in which students use strategies, observe what transpires, and search for alternative solutions provide rich examples of how metacognition is applied. Dym and Little[22] contended that the design process consists of five phases: problem definition, conceptual design, preliminary design, detailed design, and design communication. This five-step design process was used to reflect students' cognitive strategies which include activities such as (1) defining the scope of the design problem, (2) creating a conceptual design, (3) creating a preliminary design, (4) creating a detailed design, and (5) documenting the design process. A similar model was proposed by Christiaans[23] and Cross[24]. These design phases are considered high-level overall views of design processes. They involve a sequence of actions or design strategies, which are self-contained cognitive approaches and relate to the current state of the design process. For example, during a problem definition phase, students may need to analyze what their design problem entails. The problem may then be divided into several subsets. They may also need to analyze and evaluate the problem. After clearly understanding the problem, they may be ready to propose a solution, analyze it, and decide whether to use it or find alternatives.

3. The Study

The focus of this exploratory study was to evaluate the extent to which students' task interpretation of the design project is reflected in planning, cognitive, monitoring, and regulating strategies. In this article, the assessment method of the students' self-regulated learning (SRL) strategies was limited to the use of survey instrument. Butler and Cartier's[14] SRL model was used to evaluate the dynamic and iterative interplay between metacognitive and cognitive activity. The SRL dimensions of design process and task management were evaluated.

3.1. The Study Participants and Context of the Design Activities

Participants were freshman engineering students in an introductory engineering graphics course at Utah State University. The course is required in the pre-professional mechanical engineering program and the students use solid modeling software to develop and model a variety of objects. Lessons begin with simple extrusion exercises and eventually progress to complex assemblies, proper document generation and dimensioning based on ANSI and ISO standards. The class culminates with an introduction to finite element analysis. There were 45 students enrolled in the design course at the time of this study, but only 12 agreed to participate in the study. Student participation was voluntary. The limited number of participating students was acceptable for this study as it was exploratory in nature.

The course delivered a curriculum that emphasized open-ended, ill-structured[25] design problems as a capstone activity worth 20% of the student's course grade. Students begin the semester learning how to use the software competently and then engage in a design project requiring the development of a manufacturing robot. Students were given approximately six weeks to work on the activity. Specifically, students were asked to mechanically design and model a “gripper” and accompanying robotic arm for a pneumatically activated robot. Students are expected to accomplish this task using a solid modeling software package. They are given a theoretical background or setting for the design requiring it to be implemented in an assembly line scenario. The robot is expected to transport either a golf ball or standard #2 pencil between pick-up and drop-off locations on this assembly line. The gripper design must be versatile enough to accommodate both objects’ geometry with no changes to the robot’s structure. As the focal point of the robotic design, the gripper is where students exercise much of their creativity and personal flair.

Other design requirements include the work envelope dimensions for the final design and the pneumatic cylinder suppliers. Students were provided with a base assembly consisting of an example actuator and a foundation plate to construct their robotic assembly on. This base assembly defined a work envelope width and depth that students where to adhere to when the robot was transporting the parts. The height dimension of the work envelope is subject to the students own desires and considerable variability has been observed in solutions. The robotic arm is expected to retrieve the pencil or golf ball from a location outside of this work envelope and to then rotate and deliver the object to a new location in the theoretical manufacturing process. Students were supplied with a catalog of pneumatic cylinders that they were expected to utilize for actuating purposes. By providing students with a supplier’s catalog of cylinders, students with limited mechanical background were able to visualize the components and subsequently model them in their design. Prior to submittal, students are encouraged to verify part interaction and final solution viability by modeling motion on the full assembly.

Students were given no training in metacognitive strategies during the course or prior to the activity. Student final designs were evaluated by their adherence to the design restriction (e.g., gripper design must hold pencil or golf ball, work envelope, design must be pneumatically actuated, proper fasteners used, appropriate attachments, economy of design). In addition students were graded upon their successful answers to three journal entrée questions. Students were expected to also submit *jpeg* images and *avi* clips as evidence substantiating their journal question answers. Journal entrée comprised 22% of the design grade while 78% is based on successfully meeting the design objectives.

3. 2. Instrumentation

Data were collected from Engineering Design Questionnaires (EDQ). Three versions of an Engineering Design Questionnaire (EDQ) were developed to capture students’ perception of their metacognition at the early (with a prefix “E” added to the survey item number), middle (with a prefix “D” added to the survey item number), and final (with a prefix “F” added to the survey item number) stages of the design task, respectively. This questionnaire was adapted from the Inquiry Learning Questionnaire (ILQ) by Butler and Cartier based on their theoretical model[14, 15, 16, 26]. The ILQ was developed, pilot-tested, validated, and used in previous research to capture the relationships among the main features (i.e., task interpretation, personal goals, strategies, and criteria) of the SRL model (see Figure 1) for postsecondary students engaged in inquiry learning in first-year Biology.

Each version of the EDQ captured different main features of the SRL models; the first version of EDQ captured task interpretation, personal goals, and planning strategies; the second version captured cognitive strategies and other aspects of planning strategies; the third version captured students' judgment of their design outcomes. Measurement scales of EDQ items ranged from 1 to 4 (i.e., 1 = never, 2 = sometimes, 3 = often, and 4 = always).

Some EDQ items were negatively worded and the ratings ought to be reversed before an individual's score was computed. If an item had to be reversed, a person who chose 4 for that item now received a score of 1. The simplest way to reflect a negatively worded item was to subtract the original score from 5.

3.3. Data Collection Procedures and Analysis

Data were collected from 12 students in an Engineering Graphics course in the spring 2010 semester. These students were asked to complete metacognitive questionnaires (i.e., EDQ) throughout the design project (i.e., at the early, middle, and final stages of the project).

Data collected from the EDQ were evaluated quantitatively and qualitatively using a graphical view in three different ways. First, the questionnaire items were clustered based on three design stages. The mean values of all SRL items for each episode were calculated. Second, the mean values of each item from the same SRL dimension (i.e., design process and task management) were compared across SRL episodes (e.g., task interpretation, planning strategies, etc.). Third, the transitions of each questionnaire item across SRL episodes were evaluated in a graphical view. These transitions of items were conducted by item mapping analysis that explores the relationship of items across SRL episodes. For example, any item that has an average score of 3 (often) or higher (always) was considered a high score with strong identification. In contrast, an average score below 3 (i.e., never or sometimes) was considered low and far less strongly identified.

4. Findings

The findings are organized into three parts or sets of SRL episodes: task interpretation, planning strategies, and cognitive strategies; monitoring and regulating strategies; and criteria of success and task value.

4.1. Task Interpretation, Planning Strategies, and Cognitive Strategies

From the data collected at the early stage of the design project, it is apparent that the students scored very high (M = 3.05, SD = 0.52) on overall task interpretation aspects; they were highly aware of what they were required to do to solve the design problem (see Figure 2). They were particularly aware that they needed to come up with alternative ways to investigate the problem, get a good overview of the design task, understand key information about the design task, figure out the best way to investigate the design task, identify concepts, mechanism, themes related to the design task, and see how all of the information about the design task fits together. Despite their high awareness on those issues, the students did not seem to be aware of the need to explore how others had previously tackled similar design tasks. On this particular issue, the students scored an average of 2.38 (SD = 0.53).

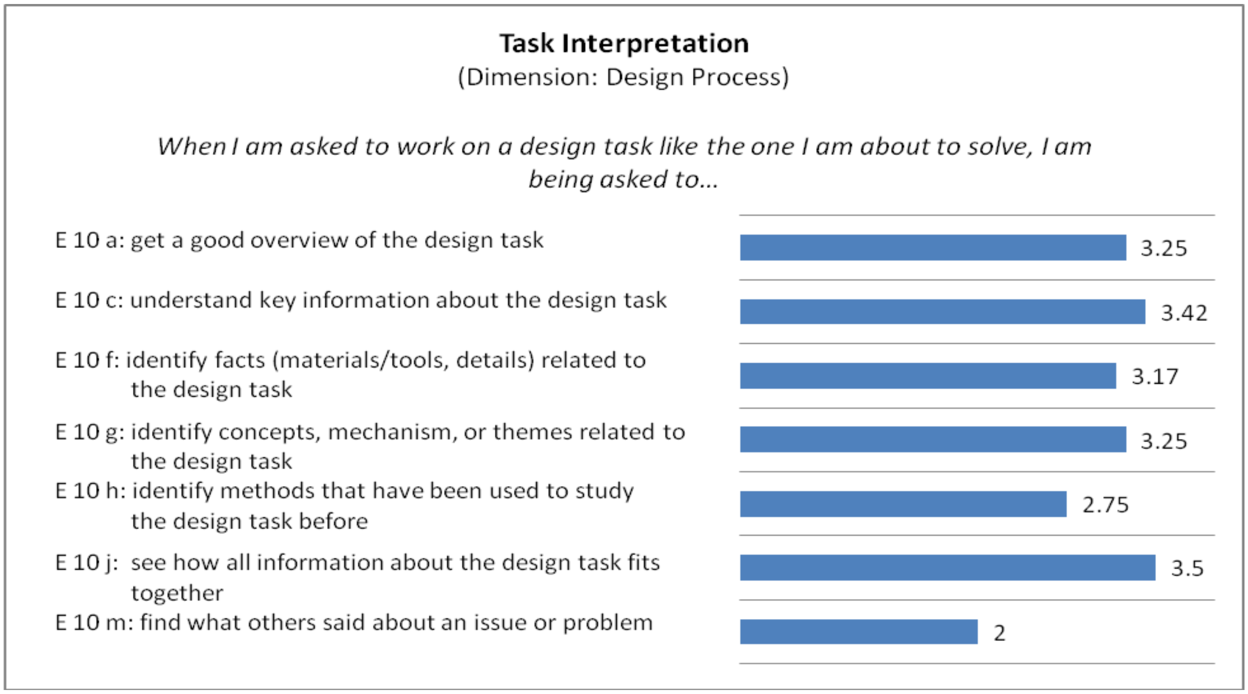


Figure 2. Task Interpretation Items and Scores

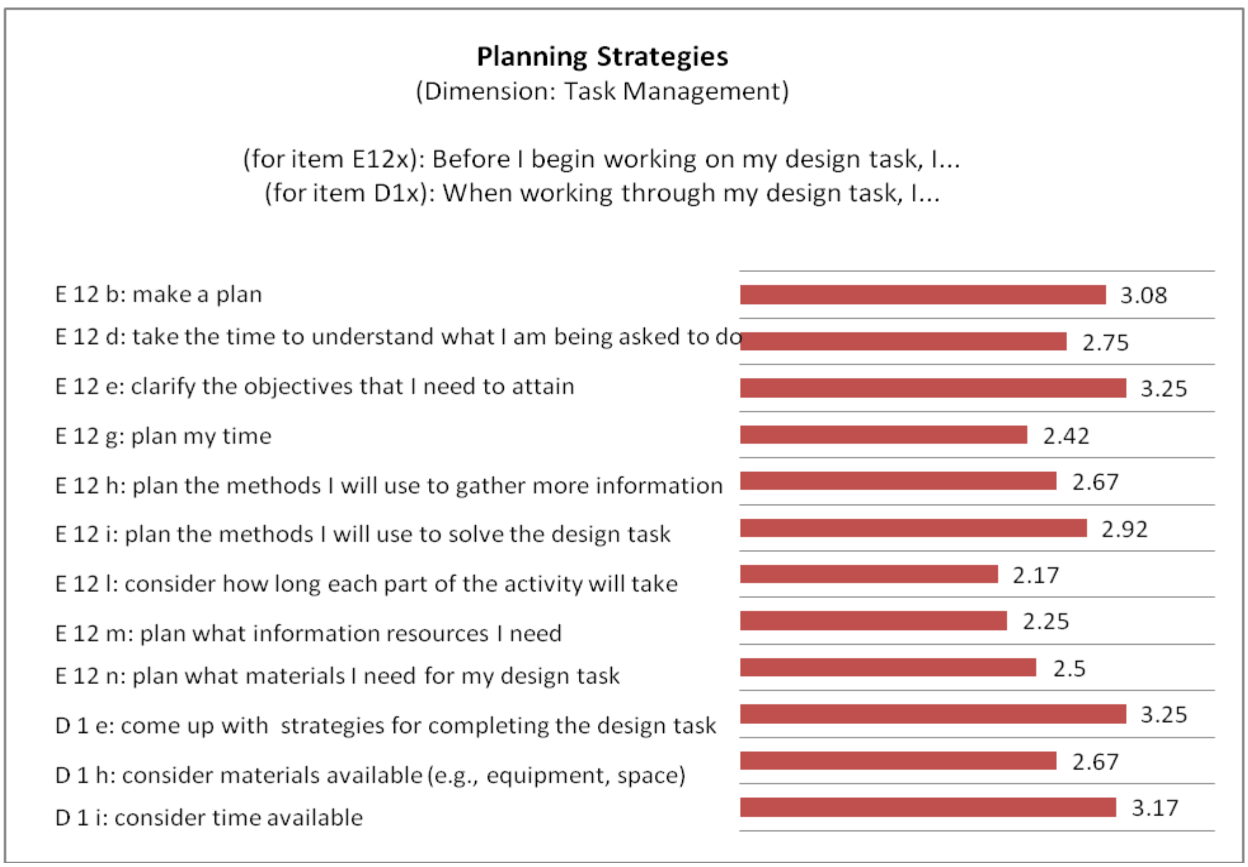


Figure 3. Planning Strategies Items and Scores

Compared to students' high awareness of the task demand, the average score for their planning strategies was relatively low (i.e., scores ≤ 3). At the early stage of the design project, the students demonstrated their awareness of the need to plan and clarify the design objectives that they needed to attain; however, they showed low awareness on specifically planning the time, methods, and materials to be used (see Figure 3). During the project, students improved in planning their time (i.e., from a score of 2.42 to 3.17) and using methods to solve the design problem (i.e., from a score of 2.92 to 3.25). A smaller increase of awareness was demonstrated in thinking about the use of materials needed in the project (i.e., from a score of 2.5 to 2.67).

As for students' cognitive strategies, it is clear that students considered creating a conceptual design as an important strategy during their project (M = 3.17, SD = 0.39). It is interesting to note that students did not consider design strategies such as defining scope of the design problem (M = 2.67, SD = 0.78), creating a preliminary design (M = 2.83, SD = 0.83), creating a detail design (M = 2.5, SD = 0.52), and documenting the final design (M = 2.67, SD = 0.98) as often as thinking about a conceptual design (see Figure 4).

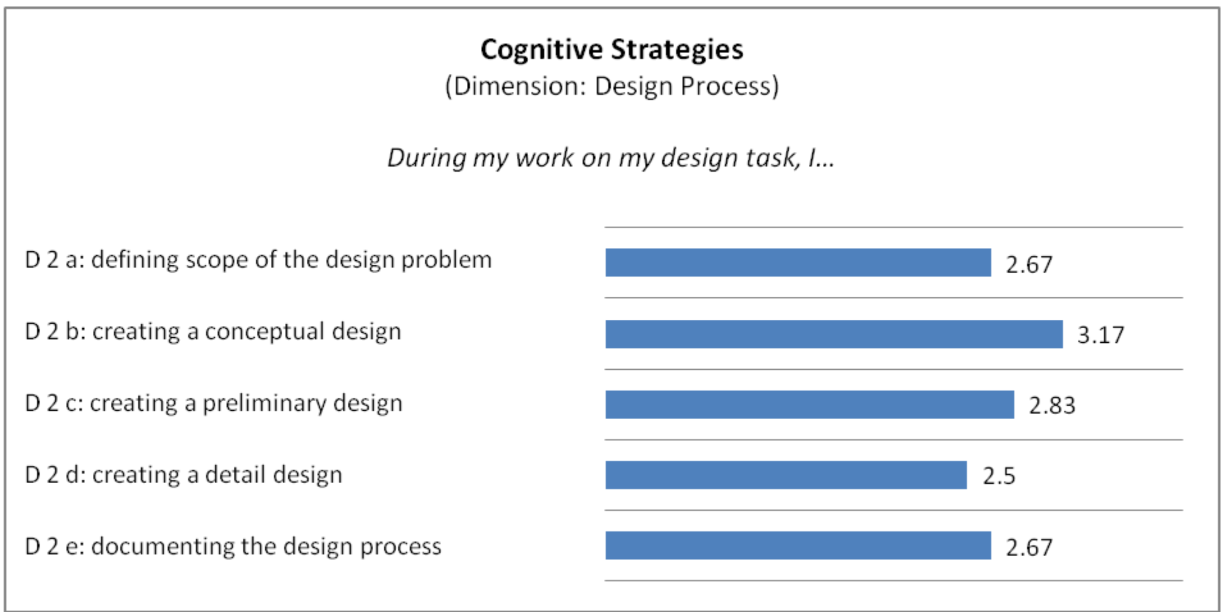


Figure 4. Cognitive Strategies Items and Scores

4.2. Monitoring and Regulating Strategies

During the design activities, the students monitored and made adjustments to their design processes and task management quite well except on the following issues: (a) seeking possible alternative design solution, (b) finding what others have said about the topic, (c) judging whether they picked the most important information, (d) judging whether they can describe what they are working on in this design task and why, (e) searching for methods others have used for similar design tasks, (f) considering effective use of resources and materials, and (g) concentrating and focusing on one activity or design step at a time. The students' complete responses on monitoring and regulating are shown in Figure 5a and 5b. It was also interesting that students seemed to be consistent in their judgment about what they thought were important activities for monitoring and regulating.

4.3. Criteria of Success and Task Value

It would be expected that having a complete understanding about the task demands would help students to achieve good design performance. The findings suggest that the students focused more on task management issues in evaluating their criteria of success than on the design process itself. Students did not seem to consider issues such as understanding all information, finding facts and concepts about the design task, drawing design methods from other people, and finding the best current knowledge about the design task as essential elements to measure success for their design project. On the contrary, they felt that doing their best, figuring out how all information about the design task fit together, responding to design requirements, and completing the task on time were some of the important key issues for their success (see Figure 6a and 6b).

Students' perception about the criteria of success for their design project should be manifested in the amount of monitoring and regulating efforts they use to yield good design performance. Linking students' task interpretation to the criteria of success reflects the extent to which their consistency in carrying out their tasks correlates to producing good design performance.

With regard to students' perception about task value (see Figure 7), it is clear that students were relatively successful in maintaining interest and positive attitude toward the usefulness of the design project throughout the design process. The findings also suggest that with the evolution of the project, the students became increasingly aware of the importance of the design project.

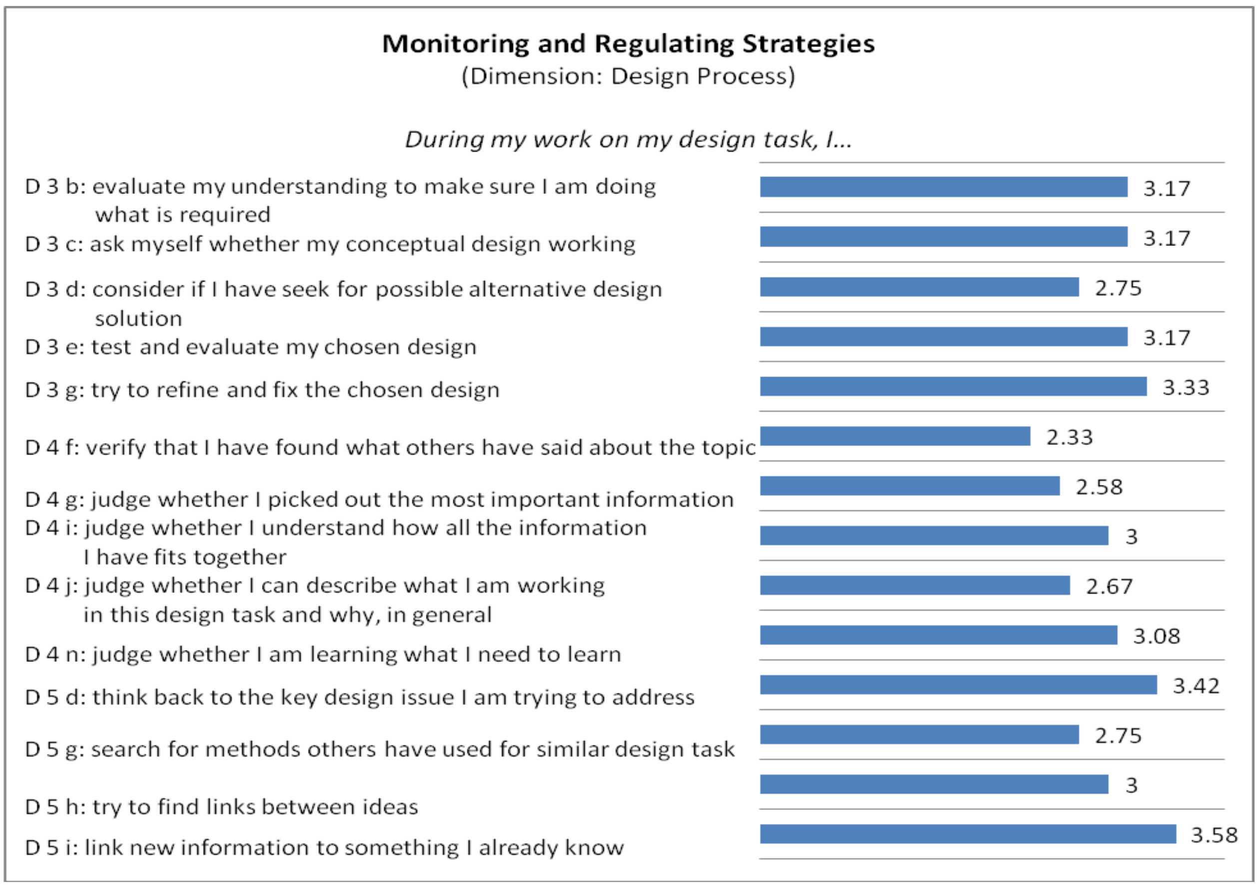


Figure 5a. Monitoring and Regulating Strategies Items and Scores (*Design Process*)

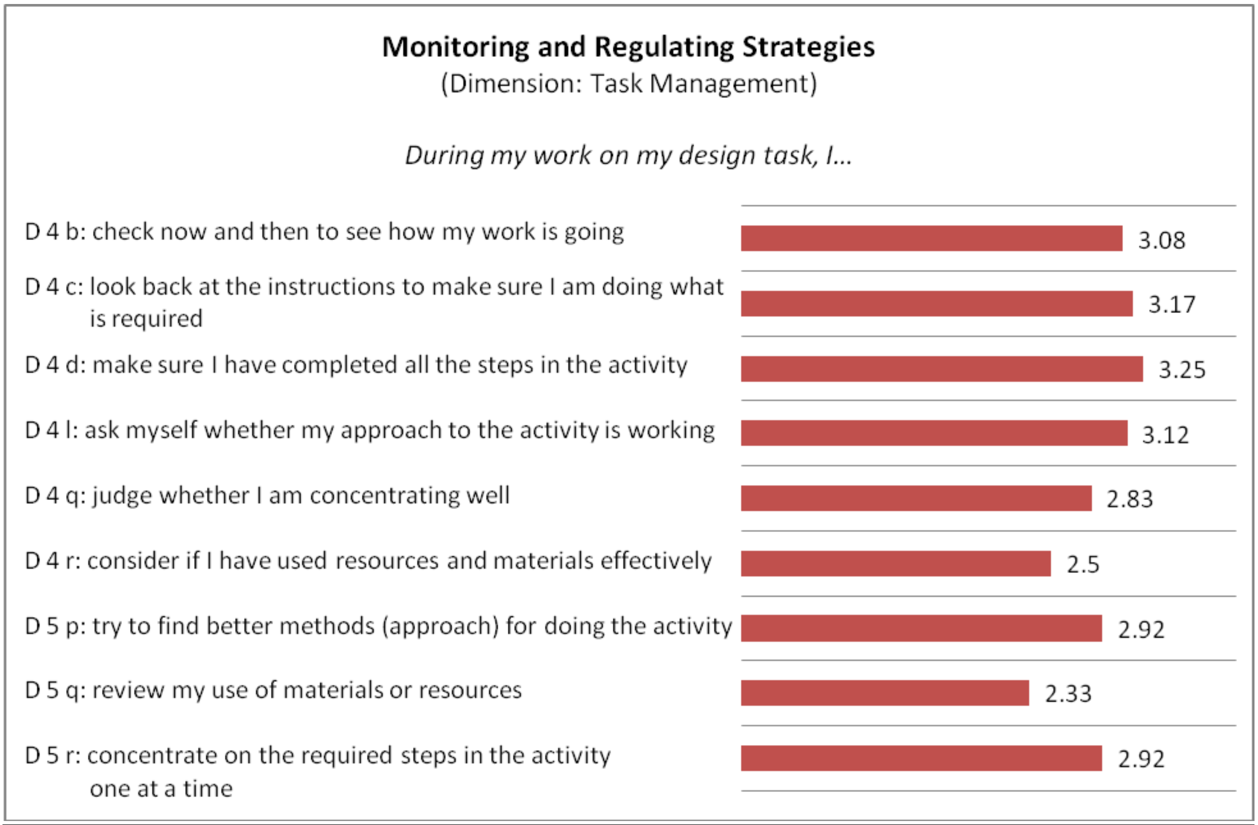


Figure 5b. Monitoring and Regulating Strategies Items and Scores (*Task Management*)

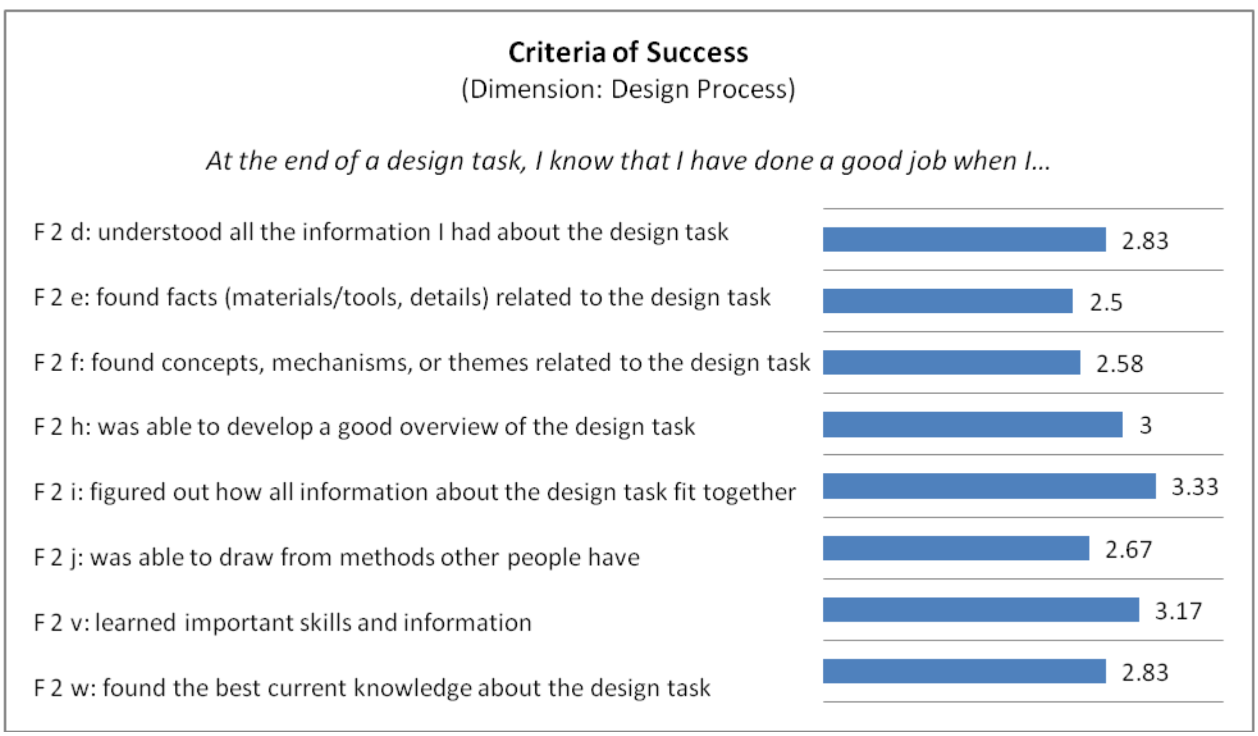


Figure 6a. Criteria of Success Items and Scores (*Design Process*)

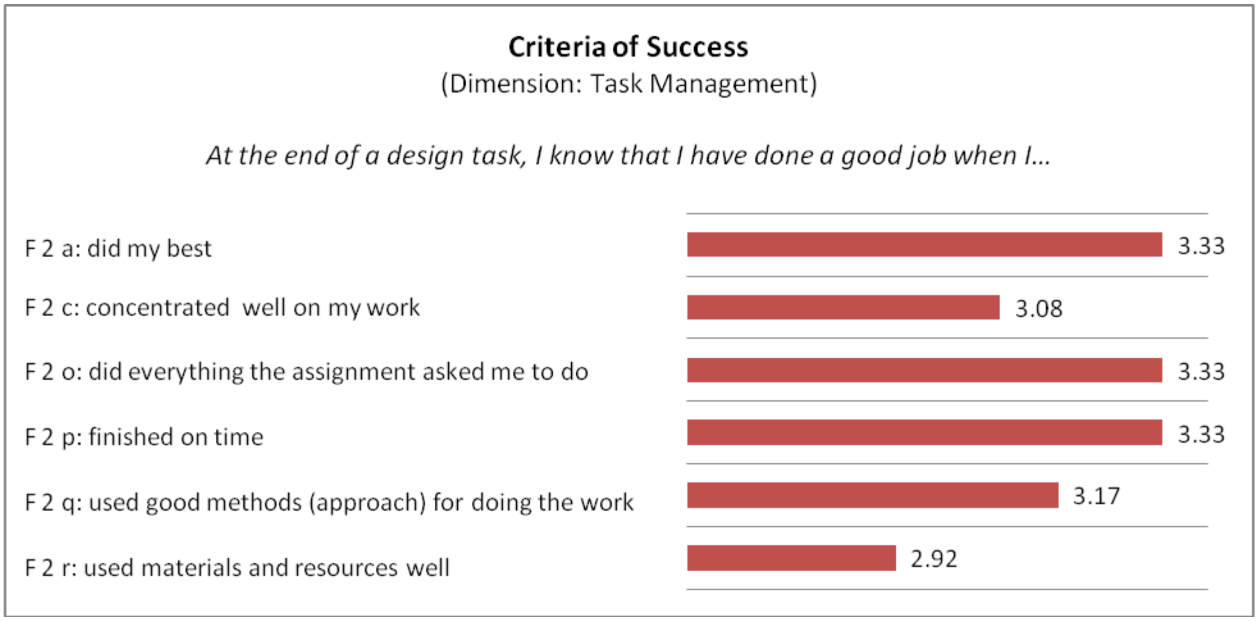
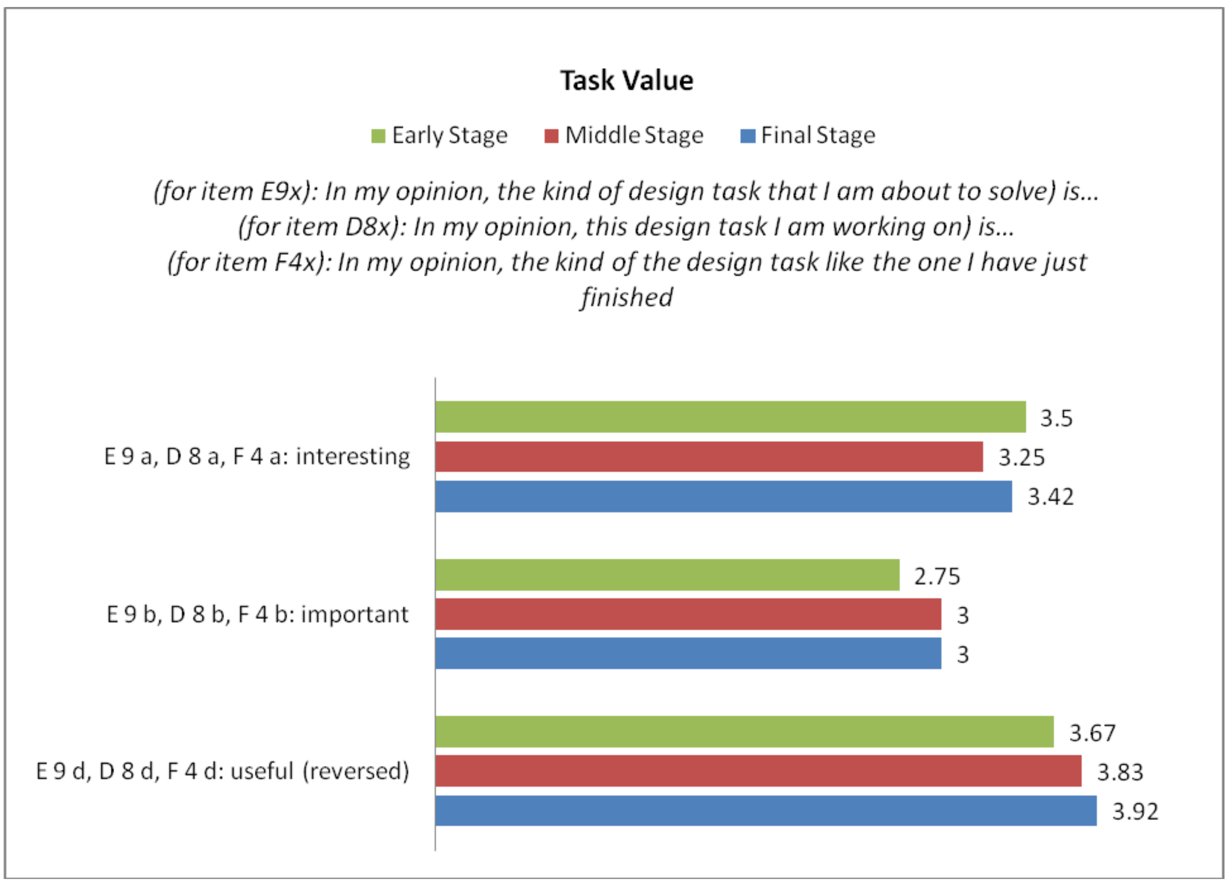


Figure 6b. Criteria of Success Items and Scores (*Task Management*)



Note: Questions about task value were questioned three times (i.e., early, middle, and final) using different wording of question. Original scores that represent "useless" was reversed and now presented as "useful."

Figure 7. Task Value Items and Scores at the Early, Middle, and Final stages

5. Conclusion and Discussion

The findings suggest that despite showing a high awareness of the various activities that they were about to encounter, students exhibited a low awareness on developing specific strategies such as time planning, and brainstorming the methods and materials to be employed. It is also worth noting that although students seemed lacking in both the initial planning methods used and initial anticipated time required to solve the problem, they were very much aware of the need to consider the time available to complete the project during the middle stage. This finding indicates students' lack of skill in predicting the amount of time required to solve the design problem during early design stages. Time does not seem to be one of the essential variables considered by the students until later in the project. It may, therefore, be advantageous for students to become more skillful in predicting and planning the time requirements needed to solve design problems at initial design stages as well as developing other task management strategies such as taking the time to understand the problem to be solved, planning the use of information resources, and recognizing required materials.

During the design activities, the students were cognizant of alternative design possibilities, but did not effectively research existing information from other design solutions to similar design problems. This phenomenon may indicate a high self-confidence by students in applying their own skills and creativity. Unfortunately the derivation of a better solution is not solely reliant upon a student's self confidence[27, 28]. However, from a motivation perspective, having good self-confidence is certainly beneficial for solving ill-structured problems such as a design task. Motivation will also help students persist in dealing with difficulties and finding better solutions. From the SRL perspective, students are expected to be confident in seeking alternative design solutions as part of their monitoring and regulating skills. Students also need to be familiar with previous methods used by others in solving similar design tasks. It follows logically (see Figures 5a and 5b) that students' low awareness in monitoring strategy leads to a low awareness in regulating strategy as well.

Students also exhibited a low performance level in effectively planning for the utilization of resources and materials to be used in solving the design task. This finding might be influenced by the nature of the project design restrictions requiring students to use specific software. The skill in using the software did vary among the students. Students coming from a secondary education system utilizing some form of parametric modeling software demonstrated an advantage over those who did not. Some students reported software learning difficulties and exhibited a higher degree of stress than those who had operated a similar CAD program before. Those who spent significantly more time learning how to use the software did not seem to perform as well on the design problem as those with more experience in their modeling software skills. Assessing students' prior knowledge and skills in using the tools involved in this design project (i.e., Solid Edge software) might prove beneficial to students and instructors alike. A form of assessment regarding student feelings and confidence about the software prior to starting the project may also be beneficial to the instructors so they might tailor individualized help to students exhibiting a lack of confidence in this area.

Inasmuch as this study is exploratory in nature, the researchers need to address two issues to improve future work in this area. First, further improvement of EDQ is needed. The current

EDQ was adapted from the ILQ by Butler and Cartier based on their SRL theoretical model. As the researchers experienced difficulties (e.g., emergence of some items in different episodes) during the analysis process, an additional adaptation of the ILQ for the design context will be needed. The next improvement step will also involve Dym and Little's[22] design process as a starting point of the adaptation process. The design process will be used as 'core' questionnaire statements. Second, after improving the instrument, the researchers plan to repeat the study with a higher number of participants. Increasing the number of participants is essential in any quantitative study in order to minimize attrition level, and represent the overall population[29].

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