Pattern of Task Interpretation and Self-Regulated Learning Strategies of High School Students and College Freshmen during an Engineering Design Project

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Abstract

The objective of this exploratory study was to describe patterns in self-regulated learning (SRL) for both high school students and college freshmen while engaged in a design activity. The main research question guiding this study was: How did high school and first-year college students self-regulate their approaches to learning when engaged in an engineering design project? Specific focus was given by exploring how these two groups of students engaged in (1) task interpretation in relation to reported strategy use during the design process; and (2) task interpretation in relation to reported strategy use in project management.

Students at one high school in the state of Colorado and first year undergraduate engineering students at one public university in the state of Utah participated in this study. High school students worked in an Architectural and Robotics Design classes (n=27). College freshmen worked in a mechanical engineering solid modeling course (n =70). A survey instrument and Web-based design journal entries were administered at early and later stages of the project to capture students' SRL, including task interpretation (*TI*) and reported use of planning (*PS*), cognitive (*CS*), and monitoring/fix-up (*MF*) strategies. Descriptive statistics, nonparametric statistics, and graphical views were used to analyze survey responses. Entries from students' design journals were segmented and coded using an SRL model and interpreted to triangulate and complement survey data to achieve better insight about the employed strategies of these two groups.

Not surprisingly, findings suggested that, for the most part, first-year college students scored higher than high school students on task interpretation and reported use of planning, cognitive, and monitoring/fix-up strategies. Journal entries also revealed that college freshmen were more thorough in identifying and describing design strategies for their projects than were their high school student counterparts. Most importantly, differences in the quality of SRL were observed within each group, suggesting that students at both educational levels varied in their self-regulated performance. Further, while students in both groups had relatively good awareness of task demands, they were less aware of how to translate that task understanding into proper plans and plan execution across the design process and project management. This article discusses potential implications for design instruction for both groups of students.

Keywords: Engineering Design, Grades 9-12, College freshman, Metacognition, Self-regulated learning

1. Introduction

Tremendous efforts have been devoted to improving student learning in high school pre-engineering and college engineering courses. One of the critical needs for advancing student learning in these contexts, as highlighted by Bransford and his colleagues in their book, *How People Learn*, is to investigate learning process from a metacognitive perspective (Bransford, Brown, & Cocking, 2000). According to Zimmerman (1989), metacognition is heavily implicated in *self-regulated learning* (SRL) which plays a significant role in learning and is an important predictor of academic performance. Models of self-regulation typically describe how metacognitive knowledge (e.g., about tasks, learning, strategies) and metacognitive skills (i.e., self-regulating strategies used in the deliberate management of learning) interweave in the context of authentic activity (e.g., see Butler & Cartier, 2004; Cartier & Butler, 2004).

With design as a core activity in engineering, design projects have been recognized as an effective activity to support learning in science, technology and mathematics (Sanders & Wells, 2010; Schaefer, Sullivan, & Yowell, 2003). Therefore, for that specific context, design has been identified as a catalyst in STEM education. Design tasks are often constructed to involve the solving of an in ill-structured problem, which requires a high level of SRL strategies use. Baker and Dugger (1986) define design as proactive problem solving that involves experimentation and development processes. However, previous research shows that students often lack problem solving ability (Redding, 1990). As problem solving involves higher-order thinking such as monitoring and regulating strategies, challenges in problem solving reflect students' weakness in SRL strategies use.

It is generally accepted that the engineering design process is iterative and not linear (e.g., Childress & Maurizio, 2007; Dym & Little, 2009; Sheppard, Macatangay, Colby, & Sullivan, 2009). Although many scholars formulate design as a multiple stage (or phase) process, it is known that students must identify, plan, act, evaluate, and make necessary adjustments within every design step. In addition to developing competency in engineering-related tasks, students also need to acquire sufficient project management skills to ensure the success of their design project (Larochelle, 2005; Bogus, Molenaar, & Diekmann, 2005; Lessard & Lessard, 2007). These project management skills involve building good team-working skills, and managing limited and constrained resources, such as materials, money and time.

Successful engagement in design tasks does not only depend on student knowledge or skills, but also on students' awareness and use of cognitive and self-regulating strategies that are appropriate to a given task within a particular domain of study. For example, in another study that included first-year college students in science, Butler, Pollock, Nomme, and Nakonechny (2008) found that the majority of students failed to productively interpret requirements (e.g., to define a problem for study and generate strategies for investigating the problem). Also, many students attended insufficiently to important self-regulating strategies (e.g., planning). Engineering differs from many science and mathematics disciplines in its unique emphasis on creation and design and it thus becomes essential to learn how students in grades 9-12 and college levels use SRL strategies while engaged in engineering design.

It is clear that there is a vital need to help students improve their SRL strategies use through SRL support. This effort can only be conducted if we successfully capture and understand students' SRL within a particular context such as an engineering design activity. The purpose of this exploratory study was to identify patterns in high school students' and college freshmen's approaches to solving an engineering design project. By investigating the learning of both high school students and college freshmen using a common framework, we hoped to generate important information about potential strengths and challenges in engineering design performance for both groups of students.

2. Relevant Literatures

2.1 Metacognition in a Self-Regulated Learning Framework

Extensive research has been conducted to evaluate the essential role of metacognition in learning. Particular emphasis has been directed to metacognition in problem solving activity (Georghiades, 2000; Pintrich, 2002; Schraw, Brooks, & Crippen, 2005; Veenman, Elshout, & Meijer, 1997). The findings of these studies have suggested that metacognitive skill plays a significant role for students in managing their learning goals and achievements (Flavell, 1979; Gourgey, 1998; Livingston, 1997).

In general, educational psychologists have divided metacognitive concepts into two major categories: knowledge of cognition and regulation of cognition. For example, Flavell (1976) categorized metacognition into metacognitive knowledge and metacognitive experience, stating that:

> Metacognition refers to one's knowledge concerning one's own cognitive processes and products of anything related to them, e.g., the learning-relevant properties of information or data... Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects on which they bear, usually in the service of some concrete goal or objective (p. 232).

Brown (1987) described metacognition as including both knowledge about cognition and regulation of cognitive activity. Pintrich (2002) suggested that students hold metacognitive knowledge about tasks and strategies that might be used for a particular task and the conditions under which the strategies might be useful. In his framework, metacognitive control was linked to self-regulating strategies that learners use to monitor and adjust cognition and learning.

Zimmerman argued that self-regulated learners are "metacognitively, motivationally, and behaviorally active participants in their own learning process" (1989, p. 239). A model of SRL can provide an integrative framework for describing how metacognitive knowledge and metacognitive control (i.e., self-regulating strategies) interweave during authentic learning activity. Butler and Cartier's SRL model, used in this study, describes the dynamic and iterative interplay between metacognitive and cognitive activity and characterizes SRL as a complex, dynamic, and situated learning process (Butler & Cartier, 2004; Cartier & Butler, 2004; Butler & Winne, 1995). This model consists of eight major features (i.e., SRL features) that interact with each other: layers of context, what individuals bring, mediating variables, task interpretation, personal objectives, SRL strategies, cognitive strategies, and performance criteria (see Figure 1).

The first feature, *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, *what individuals bring to the context*, 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 (Butler & Cartier, 2004; Cartier & Butler, 2004; Schoenfeld, 1988). The third feature, *mediating variables*, includes domain-specific knowledge, metacognitive knowledge (e.g., about tasks or strategies), perceptions of competence and control over learning, and conceptions about academic work or particular activities (e.g., learning in Science is about memorizing current knowledge). Mediating variables also include emotions experienced before, during, and after completing a task. The fourth feature is student *task interpretation*. Task interpretation (of task demands) is the heart of the SRL model insofar as it shapes key dynamic and recursive self-regulating processes. Students' interpretation of task demands is a key determinant of the goals set while learning, strategies selected to achieve goals, and criteria used to self-assess and evaluate outcomes (Butler & Cartier, 2004; Butler & Winne, 1995;

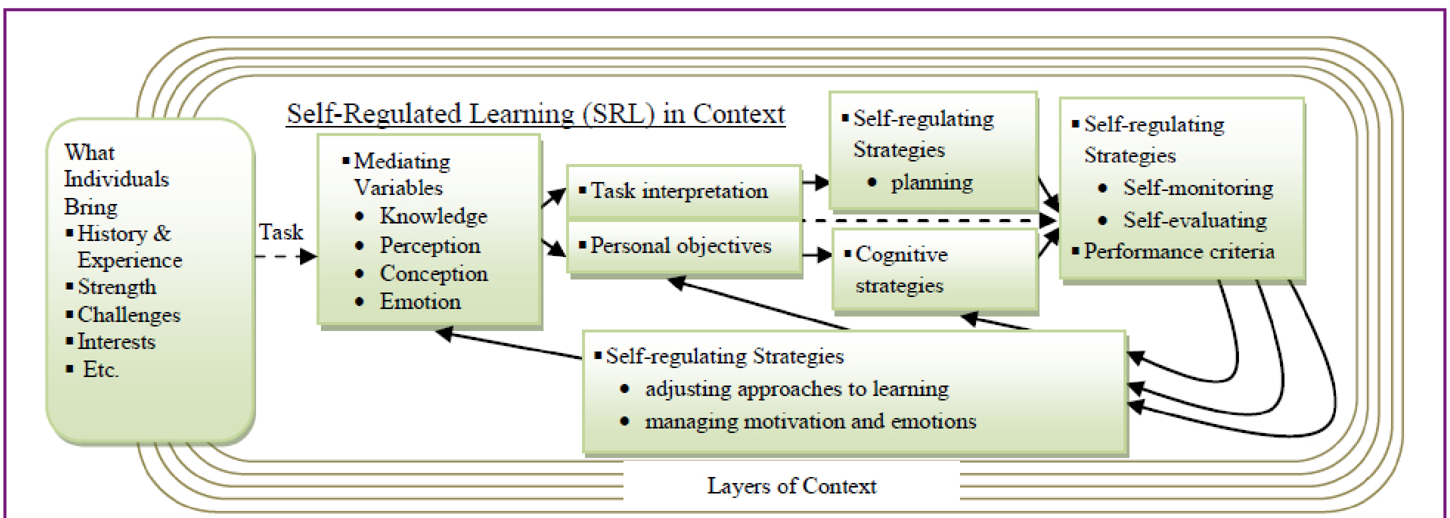

Figure 1. Self-Regulated Learning (SRL) in Context

Source: Butler & Cartier, "Multiple complementary methods for understanding self-regulated learning as situated in context," 2005

Cartier & Butler, 2004). Based on their interpretation of task demands within a particular context, and influenced by mediating variables (e.g., perceptions of competence and control), students set *personal objectives* (i.e., the fifth SRL feature) that shape their engagement. Personal objectives might be to achieve task expectations, or they might involve just "getting through" a task or even disengaging from learning.

Students manage their engagement in academic work by using a variety of *SRL strategies*, the sixth feature in the Butler and Cartier model: planning, monitoring, evaluating, adjusting approaches to learning, 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. The seventh feature, *cognitive strategies* refers to students' cognitive activities employed as they engage in their work executing the design tasks, as planned, monitored, and adjusted through metacognitive activity (i.e., self-regulating strategies). Finally, feature eight, *performance criteria*, forms the basis on which students make judgments about their achievements while working on a particular task. These achievement criteria are related to their understanding of a design task.

Self-regulated learning is particularly necessary in the context of complex and ill-structured activity for engineering design. When students are asked to engage in a complex and ill-structured problem solving, as is the case in design projects, these SRL features dynamically interact and influence how students engage within the design activity (see Lawanto 2011; Lawanto, Goodridge, & Santoso, 2011). Recognizing that task interpretation shapes key dynamic and recursive self-regulating strategies, the particular focus of this research was to explore the qualities of task interpretation for high school and first-year college engineering students (Butler & Winne, 1995). Consideration was then directed for each group towards how interpretation of task requirements in an engineering design project might be reflected in a group's working plans and reported use of planning, cognitive and monitoring/fix-up strategies.

2.2 Engineering Design Process and Project Management

It is widely believed that design is a central part of engineering activities, and through design experience students are expected to develop competency in problem-solving as well as critical and creative thinking. For this reason, Dym (1998) emphasized the need for engineering curriculum to include solving design problems. He argued that there is still a lack of "language of design" in teaching engineering students and noted that it "ought to be the prime directive of designing engineering curricula" (p. 45). Jonassen (2004) described design problems as ill-structured, involving certain features such as multiple or unclear success criteria and real-world or constrained contexts. Furthermore, he argues that ill-defined problems are more difficult to solve because they require more cognitive operations than well-defined problems.

The engineering design process, as noted by Sheppard, et al., (2009), "is not linear: at any phase of the process, the engineer may need to identify and define sub-problems, then generate and evaluate solutions to the sub-problems to then integrate back into the overall process" (p. 104). The National Center for Engineering and Technology Education (NCETE) professional development approach emphasizes eight essential elements of the engineering design process: "identification of need, definition of the problem/specification, search, development of design, analysis, decision, testing of prototype and verification of solution, and communication" (Childress & Maurizio, 2007, p. 3). Dym and Little (2009) divided the design process into five phases: problem definition, conceptual design, preliminary design, detailed design, and design communication. This five-step design process was used in this research to describe students' cognitive strategies when engaged with a design task, 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.

Studies have been conducted to assess students' SRL strategies in different groups of education. For example, while Magno (2010) and VanderStoep, Pintrich, and Fagerlin (1996) evaluated students' SRL strategies at college, Abar and Loken (2010) and Barak (2009) reported high school students' SRL strategies in technological projects and a college preparation program, respectively. In addition, Lawanto and Goodridge (2012) investigated high school students' SRL strategies from performance and gender perspectives. However, there is limited research on how SRL strategies are strong or challenged across high school and college groups while students are engaged in solving design projects, particularly as examined from the perspective of a common engineering design model. This study may also give insights into bridging strategies between high school students and college freshmen regarding their SRL while engaged in engineering design activities.

In this study, we focused on the first two design phases within the Dym and Little model: *problem definition* and *conceptual design*. Emphasis was placed upon these two phases because students' success in understanding the objectives of the project and how they conceptually solve a design problem has a significant impact on the subsequent three design phases. According to Dym and Little (2009), each main phase is divided into several sub-phases. For example, the problem definition phase consists of four sub-phases including clarifying objectives, establishment of metrics for objectives, identification of constraints, and revision of a client's problem statement. Students within this particular study were given no option to change or revise any part of the design task, which was targeted by the instructor as part of course requirements. As a result, this study does not consider the last sub-phase (i.e., revision of a client's problem statement) from the first design phase. The second phase, conceptual design, involves six sub-phases. Specifically these sub-phases include the establishment of functions, requirements, and means for functions, the generation of design alternatives, refinement and application of metrics to design alternatives, and the choosing of a design solution. This study therefore targets nine sub-phases out of Dym and Little's ten possible sub-phases across the problem definition and conceptual design phases.

Successful team design projects also depend upon the project management skills of every team member (Larochelle, 2005). The Program Management Institute (1996) defines project management as "the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stakeholder needs and expectations from a project" (p. 6). Larochelle (2005) makes a noteworthy statement when suggesting that project management skills need to be introduced to engineering students especially in the early years of engineering education at the college level. While we used the terms 'design process' to indicate the technical content (e.g., what does the robot have to do, how do we design that), we put forward the term 'project management' to reference students' efforts in managing the project as a whole (i.e., how much time do we have to solve this design problem, what resources do we need). Various studies have been conducted to evaluate targeted areas of project management including time, resources, and teamwork. For example, a study conducted by Bogus, Molenaar, and Diekmann (2005) suggested that a concurrent engineering approach can be applied to reduce time for completing a design project. Lessard and Lessard (2007) outlined technical knowledge, creativity, people skills, planning abilit, and management skills as essential ingredients in an effective engineering team. In this study, we considered how SRL was implicated in student management of the overall design project and in particular on issues such as time, resources, and teamwork.

3. The Study

Butler and Cartier's SRL model (Butler & Cartier, 2004; Cartier & Butler, 2004) was used to evaluate the dynamic and iterative interplay between metacognitive and cognitive activity during the design processes and management of design projects. The main research question set forth to guide this study examined patterns in the ways that high school students and college freshmen engaged in engineering design projects. Attention focused on the qualities within and between groups of: (1) task interpretation related to students' strategy use during the design process; and (2) task interpretation related to students' strategy use in project management.

3.1. The Study Participants and Context of the Design Activities

Participants were students at a high school in Colorado and first-year engineering students at a large public university in the state of Utah. Twenty-nine and 70 students were sampled in each setting, respectively. Student participation was voluntary and students were given no training in cognitive or self-regulating strategies before or prior to the design activity.

Because SRL is contextual as suggested by Butler and Cartier's SRL model, there is a need to explain similarities, differences and levels of difficulty for the design projects assigned to the two groups. Design projects for both groups were similar in terms of the ill-structured format of the activity. In both groups, students worked regularly on projects across a 3- or 4-week period. Specifically, high school students worked on their design project every day during class sessions across three weeks; college freshmen worked on their projects in class several times a week across a four-week period as well as outside of class with times that fit within their academic schedule. High school students were expected to build a real working robot and physical model of a house from design sketches. College freshmen were asked to design a gripper and robotic arm in solid modeling software by following specifications from industry, but were not required to develop the full robot.

3.1.1 Design Project at the High School Level

At the high school level, two design classes were chosen to provide the context for the design tasks for this study: Robotics and Architectural Design (see Figure 2). These classes met four times a week and were taught by the same teacher. There were 27 students, aged 15 to 18, enrolled between the two classes. No student was enrolled in both classes. In each class, students were given a final design project to be completed in three weeks. The requirements of the design projects were created by the teacher. A brief description of each project is presented below.

3.1.1.1. Robotics Design

Students were required to work in teams 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 was on the creation of a robotics team to represent the high school at local, regional and national events, such as the FIRST Robotics Competition. The design process for the robotics challenge was taught in the following steps: *First*, students were encouraged to ask questions, probe into what was allowable and what was not, and to look for loopholes in the rules. If the robot was to manipulate an object, students were asked to handle that object, feel it, weigh it and/or measure it, thus providing a physically interpreted understanding as to what the robot was being asked to do. *Second*, students were asked to come up with a diverse list of possible solutions. During this phase students were encouraged to talk to one another, sketch, and create simple prototypes demonstrating a solution. *Third*, once a concept had been reached, students were required to work out the details of design using a standard solid modeling computer-aided design (CAD) package (i.e., SolidWorks). *Fourth*, once potential bugs had been explored and worked out in the solid modeling CAD software, the robot was built. During this stage, programming of the robots also began. Students were taught to work modularly in sub-groups. *Fifth*, students were encouraged to discover programming flaws and inadequate construction (dropping wheels, nuts and bolts on the table during test runs) and conduct necessary revisions. The three-week period for robotics was split up into three segments, with a week to design (steps 1, 2 and 3 from above), a week to build and a week to test their robots.

3.1.1.2. Architectural Design

In this class, students were expected to produce a nearly full set of house plans typical of the residential drafting industry. The nature of the Architectural Design challenge necessitated a slightly different design problem structure to the three-week time period. *Week one* was comprised of an allotted time to consider project requirements and come up with a plan that met all of the client's requirements. This was done using manipulatives to explore shapes, and pencils and graph paper to sketch out ideas. Students had been taught to work from a general idea to a more specified one. During the first week, they employed this technique implementing a dimensioned design on graph paper that was then ready for further refinement within the CAD package. *Week two* was strictly devoted to generating the design in CAD. As with the robotics class, students were encouraged to stay with the basics and not to proceed above their current skill set with the software. *Week three* incorporated the building of physical models using mat boards, hobby knives, glue and hobby landscaping materials.

Figure 2. An example of Robotics and Architecture design project

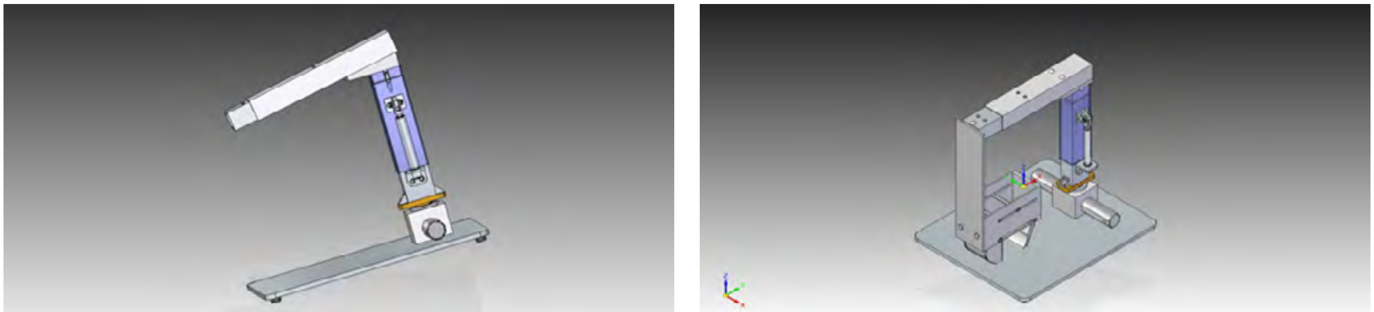

Figure 3. An example of gripper design progress (Week #2 and #4)

3.1.2 Design Project at the First-Year College Level

The first-year college course delivered a curriculum that emphasized open-ended, ill-structured design problems as a capstone activity. Students began the semester learning how to use the software competently and then engaged in a design project requiring the development of a manufacturing robot using a solid modeling software package. Students were allotted 4 weeks to complete the design activity. They were required to track their progress in weekly journal entrees, answering four questions about their perceptions and progress on the design. The main focus of the activity was towards the gripper and arm components of the robotic arm (see Figure 3). The design of the former required enough versatility in its application to successfully be modeled around two distinct assembly line products without requiring a change in the gripper mechanism. Students were initially given a theoretical background or setting for the design requiring it to be implemented in an assembly line scenario.

Designs were constrained with a provided set of conditions typical to those seen in industry where a design must target a certain working environment and/or cost. Some of these constraints included width and depth dimensions of the robotic arm's work envelope for both operating and resting scenarios, the type of actuators available for use on the robotic arm (in the form of a supplied pneumatic actuator catalog), and general material parameters such as industry typical material cross sections or types of materials that the robotic arm should be created from. This forced the students to ground solutions upon feasible and realistic supplies and components. Students were encouraged to verify part interaction throughout their design process. Final submission of a design required students to verify all part interactions on the completed assembly thus ensuring prototype solution viability. Full motion was initiated through the application and simulation of modeled motors applied to appropriate locations on the robotic solution.

Solutions were analyzed by their adherence to design constraints, the successful modeling of the robotic arm demonstrated to the instructor, and the completed journal of the design process exhibiting not only written entrees but also *jpeg* images of the different stages of design. Design constraints included the gripper design accommodating two separate part geometries, the work envelope width and depth, the design being pneumatically actuated, use of the proper fasteners, and the use of appropriate attachments. The images required with journal entrees substantiated what was written with a form of physical evidence ensuring the work was actually done at that point. Journal entry dates and times were also automatically logged. Robotic arm demonstration was accomplished through inspection of the solution by the instructor as well as student demonstration and the recording of *avi* files of the robotic arm in appropriate movements.

SRL Features and Examples in the Context of Defining the Design Project

Features	Examples
Task Interpretation	• When I am asked to work on a design task like the one I am about to solve, I am being asked to understand the action or goal for which my design must perform.
Planning Strategies	• Before I begin to work on the design task, I identify the measures that make a good design performance.
Cognitive Strategies	• When working on this kind of design task, I establish a way to measure how well I am reaching the design objectives.
Monitoring & Fix Up Strategies	• During my work on my design task, I make sure whether I used an appropriate method to measure how well the design objectives are met.

Table 1

3.2. Data Collection Procedure and Analysis

In this study, two assessment methods were used to gather information on students' task interpretation and SRL strategies: the Engineering Design Questionnaire (EDQ) and student design journals. Data from the EDQ were collected three times throughout the project: at early (i.e., first day of the project), middle (i.e., end of the third week), and final stages (i.e., last day of the fourth week) of the project using Qualtrics™, an online survey media. The EDQ was administered by the teacher and students completed those surveys in class. Students' design journal entries were regularly collected online as students worked through their projects.

3.2.1. Self-Regulated Learning Survey: Engineering Design Questionnaire (EDQ)

The EDQ used in this study was adapted from the Inquiry Learning Questionnaire (ILQ) of Butler and Cartier based on their theoretical model (Butler & Cartier, 2004; Cartier & Butler, 2004). Two subsections of the EDQ were used to capture students' task interpretation and reported SRL strategies at both early and approaching the final stages of the project.

Each subsection of the EDQ captures different features of the Butler and Cartier SRL model; the first subsection captures students' task interpretation and reported use of planning strategies; the second subsection captures students' reported use of cognitive strategies as well as monitoring and fix-up strategies (see Table 1 for a sample of the survey items). Measurement scales of EDQ items ranged from 1 to 4 (i.e., 1 = *almost never*, 2 = *sometimes,* 3 = *often*, and 4 = *almost always*).

The EDQ used in this study was developed, pilot-tested and validated as part of previous research (Lawanto, 2011; Lawanto, Goodridge, & Santoso, 2011) involving high school and first-year college students engaged in design projects. In order to identify the internal reliability of the EDQ constructs, an ex-

Cronbach's Alpha Scores			
General Category	Dimensions	# of Items	Cronbach's Alpha
Task Understanding	Task Interpretation (*TI*)	9	.80
Self-Regulating Strategies	Planning Strategies (*PS*)	9	.77
	Monitoring & Fix Up Strategies (*MF*)	20	.91
Cognitive Strategies	Cognitive Strategies (*CS*)	25	.91

Table 2

ploratory factor analysis was conducted. Table 2 shows that, where applicable, all dimensions had very high Cronbach's Alpha scores.

As a first step in analyzing data from the EDQ, the survey data were evaluated for irregularities. Specifically the researcher looked for anyone who responded to each survey item with the same answers (e.g., marked "4" for all items or blocks of items). Two suspiciously completed surveys were identified for high school students that required the researcher to further investigate the validity of the responses. Conflicting responses were found within personal objectives items as well as between personal objectives and SRL strategies items. As a result, we excluded the two surveys from our data pool. Ultimately analyses included 27 surveys for high school students and 70 surveys for college freshmen. Next, mean values of all SRL items for each feature were calculated. To conduct comparison between means, two types of non-parametric statistics (i.e., Mann-Whitney U and Wilcoxon tests) were used because of the small sample size observed. With anticipated higher mean scores for the first-year college students in group comparisons, we chose to relax the cut-offs used to judge statistical significance to one-tailed values.

3.2.2. Design Journal Entries

Anytime students worked on their design project, they were asked to write and submit a journal entry using a Moodle-based Web-application. Students were required to write and submit at least one entry per week. Four prompts were prepared to guide the students writing of design journals: *(1) Clearly describe your present understanding about the design task; (2) List your accomplishments today. Following this identify and describe your struggles and any areas where there is a need for improvement; (3) From this point, describe your plans to continue on with your project; and (4) Describe your strategies to carry out your plans.*

The design journals provided qualitative data which were coded to reflect the SRL features in Butler and Cartier's SRL model for Dym and Little's (2009) first two phases of design processes. A segmentation process was carried out to identify whether one journal entry written by the student could be judged as one segment or more than one segment that reflected meaningful chunks of meaning. A coding process was then conducted to determine whether a segment can be categorized into a specific SRL feature of Butler and Cartier's model. Inter-rater reliability was calculated to evaluate the degree of agreement between two research assistants in segmenting and coding SRL features of students' journal entries. The inter-rater reliability was found to be at an acceptable level both for segmenting (90 percent agreement) and coding (94 percent agreement). Any disagreements between raters were reconciled before frequencies were calculated. Any qualitative differences or similarities found in SRL across the two groups were evaluated.

4. Findings

To describe patterns in SRL within and between the two groups of students, findings are presented by describing the relationships between task interpretation and reported strategy use. Analyses of quantitative and qualitative data are presented, first in relation to the design process, for the first two of Dym and Little's design phases (i.e., problem definition, conceptual design), and then for project management (i.e., time, resources, teamwork).

4.1 Task interpretation and reported strategy use during the design process

Drawing on findings from design journals and the EDQ, we described the level and quality of self-regulation within and across the two groups of students (e.g., *TI* for high school and first-year undergraduate students). The mean and standard deviation scores of both groups on the EDQ, combined across the first two phases of the design process, and broken down for each SRL feature, are presented in Table 3.

We then traced relationships among SRL features for each group of students (e.g., how levels of TI could be related to reported use of planning, cognitive or monitoring/fix-up strategies) as the design processes unfolded (from the beginning to the end of the activity). Figures 4 and 5 present the mean scores on each SRL feature for the two groups of students. Figure 4 presents data from the first of Dym and Little's design phases (i.e. problem definition), overall (panel *a*), and for each sub-phase (panel *b to d*). Figure 5 presents data from the second of Dym and Little's design phases (conceptual design), overall (panel *a*), and for each of the six associated sub-phases (panel *b*-*g*), as identified earlier.

Our findings revealed that both high school students and college freshmen consistently reported a higher TI value than any other SRL feature in each phase, as well as across subphases. For high school students, a series of Wilcoxon tests indicated significant differences between *TI* and *PS* overall ($Z = -2.910$, $p < .01$), as well as on design objectives ($Z = -3.624$, $p < .01$) and design functions ($Z = -3.377$, $p < .01$). These findings suggest gaps for high school students between understanding of task requirements and awareness of planning as an important strategy for achieving objectives. Findings also revealed significant differences between *TI* and *CS* on overall *CS* ($Z = -3.340$, $p < .001$), and on design objectives ($Z = -3.452$, $p < .001$), design metrics ($Z = -2.437$, $p < .01$), design functions ($Z = -4.101$, $p < .001$), design requirements ($Z = -1.824$, $p < .05$), and design selection ($Z = -2.053$, $p < .05$).

SRL Scores for High School Students and College Freshmen (Design Process)

SRL Feature	High school students (n = 27) *M (SD)*	College freshmen (n = 70) *M (SD)*
Task interpretation (*TI*)*	3.13 (.44)	3.46 (.37)
Planning Strategies (*PS*)*	2.76 (.61)	3.16 (.40)
Cognitive Strategies (*CS*)*	2.72 (.34)	2.92 (.41)
Monitoring/Fix-Up Strategies (*MF*)*	2.84 (.42)	3.10 (.43)

Note: * Significant at the .01 level (one-tailed)

Table 3

These findings suggest that high school students had relatively low awareness on how to execute relevant strategies related to their understanding of demands associated with design sub-phases. Finally, significant differences were also found between *TI* and *MF* overall ($Z = -2.395$, $p < .01$), and on design functions ($Z = -3.108$, $p < .01$) and design selection ($Z = -2.458$, $p < .05$). These findings suggest that, even with a good understanding about design functions, high school students sometimes failed to reliably monitor success in transforming inputs into outputs. Similarly, while high school students understood they needed to choose a design, they were less likely to report monitoring whether they chose an optimal solution.

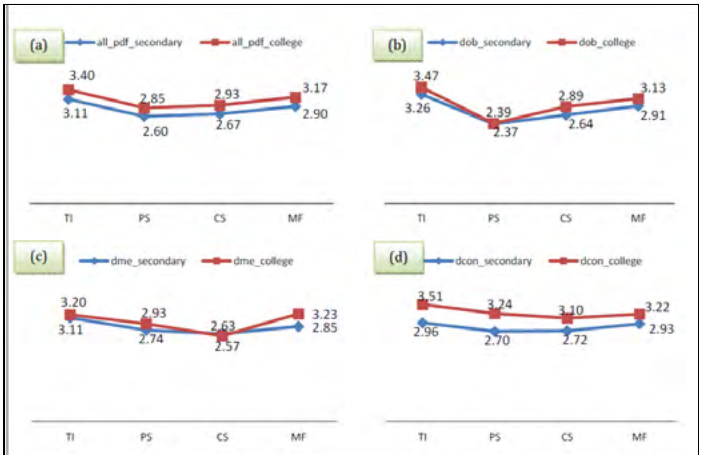

Figure 4. Problem Definition across SRL features of high school students and college freshmen: (a) all problem definition sub-phases; (b) design objectives; (c) design metrics; and (d) design constraints

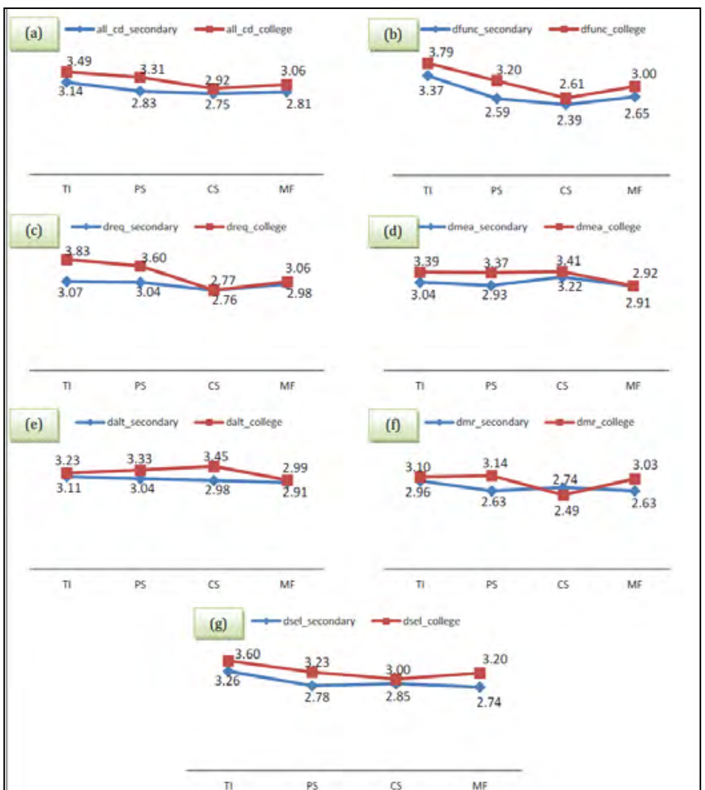

Figure 5. Conceptual Design across SRL features of high school students and college freshmen: (a) all conceptual design sub-phases; (b) design functions; (c) design requirements; (d) design means; (e) design alternatives; (f) design metrics refinement; and (g) design selection

Results for college students were similar. Scores of *TI* were higher than *PS* scores overall ($Z = -4.865$, $p < .001$), as well as on design objectives ($Z = -6.162$, $p < .001$), design metrics ($Z = -2.149$, $p < .05$), design constraints ($Z = -2.642$, $p < .01$), design functions ($Z = -5.347$, $p < .001$), design requirements ($Z = -3.411$, $p < .001$), and design selections ($Z = -2.915$, $p < .01$). *TI* differed from *CS* overall ($Z = -6.783$, $p < .001$) and on all design sub-phases ($p < .01$) except for design means. TI to MF differences were evident on overall *MF* ($Z = -5.246$, $p < .001$) and on all design subphases except for design means and design metrics refinement (with all statistically-reliable *p* values less than .05 or .01). As with high school students, these findings show significant gaps between college students' understanding of task requirements (at the phase and subphases levels), and their reported use of strategies to achieve those task demands.

Analyses of journal entries were consistent with EDQ findings for high school students. High school students focused more on task interpretation (100 segments – 31 percent) than they did on describing planning (67 segments – 20 percent), cognitive (79 segments – 24 percent), or monitoring/fix-up (82 segments – 25 percent) strategies. Chi-square tests indicated a significant difference between *TI* and *PS* ($\chi 2 = 6.521$, $p < .01$). A different pattern was found for college freshmen who described monitoring and fix-up strategies (417 segments – 36 percent) more often than they described planning (282 segments – 24 percent) or cognitive strategies (262 segments – 23 percent), and more often than they focused on task interpretation (192 segments – 17 percent). That TI was mentioned less often than MF ($\chi 2 = 83.128$, $p < .001$) for college freshmen was not aligned with what we found from EDQ data (see Table 3).

In our analysis of patterns, we anticipated that college students' self-regulation would outpace that of their younger peers. Consistent with this expectation, apparent in panel a of both Figures 4 and 5, is a better overall SRL performance by college freshmen for Dym and Little's first and second design phases. In particular, college freshmen better perceived task demands in both design phases. Specifically, during the problem definition phase, significant differences between groups in *TI* were found on design constraints ($Z = -3.318$, $p < .001$). During conceptual design, significant group differences in *TI* were observed on design functions ($Z = -3.128$, $p < .001$), design requirements ($Z = -4.833$, $p < .001$), design means ($Z = -2.115$, $p < .05$) and design selections ($Z = -1.994$, $p < .05$).

Findings at the sub-phase level also revealed significant differences between students at high-school and college levels on reported planning strategies. Here significant differences between groups were observed in the design constraints subphase during problem definition ($Z = -2.987$, $p < .05$), and in the design function ($Z = -3.510$, $p < .001$), design requirements ($Z = 3.365$, $p < .001$), design means ($Z = 2.504$, $p < .05$), design metrics ($Z = -3.028$, $p < .01$), and design selection ($Z = -2.164$, $p < .05$) subphases during conceptual design. Significant group differences on reported cognitive strategies were also found during problem definition on design objectives ($Z = -2.203$, $p < .05$) and design constraints ($Z = -3.043$, $p < .001$), and during conceptual design on design functions ($Z = -1.814$, $p < .05$) and design alternatives ($Z = -3.546$, $p < .001$).

Findings at the sub-phase level also revealed significant group differences on reported monitoring/fix up strategies. Significant differences between groups were found during problem definition on design metrics ($Z = -2.360$, $p < .01$) and design constraints ($Z = -2.170$, $p < .05$), and during conceptual design on design functions ($Z = -2.688$, $p < .01$), design metrics refinement ($Z = -2.528$, $p < .01$), and design selection ($Z = -3.554$, $p < .001$).

Differences in the EDQ findings between groups were also apparent in analyses of journal entries. Findings of journal entries were suggestive that college freshmen mentioned issues of planning, cognitive, and monitoring/fix up strategies more often than did high school students (although differences were

Number of Entries and Words between High School Students and College Freshmen

Groups of students	Total # entries	# entries/students	# entries/week	# words/entry
High school students	228	228/27 = 8.44	76	128
College freshmen	493	493/70 = 7.04	123	234

Table 4

Journal Segment Quality across Groups (Design Process)

Groups / Quality of journal report segment	High school students (∑ segments/student)	College Freshmen (∑ segments/student)
Deep, thorough, explicit*	171/27 = 6.33	948/70 = 13.54
Narrow, less thorough, non-explicit	154/27 = 5.70	195/70 = 2.79
Total segments/student	(171 + 154)/27 = 12.04	(948 + 195)/70 = 16.33

Note: * $p < .05$

Table 5

not statistically reliable). However, across the two design phases important differences in the level and quality of task interpretation and reported strategy use were evident between the groups. For example, journal entries revealed significant differences between high school students and college freshmen in terms of total entries ($\chi 2 = 97.399$, $df = 1$, $p < .001$) and the number of words per journal entry ($\chi 2 = 31.039$, $df = 1$, $p < .001$) in which SRL processes were implicated (see Table 4). Such findings suggest that the level of SRL for college freshmen outpaced that of their high school counterparts.

Further, on average, college freshmen and high school students wrote 16.33 and 12.04 segments/student, respectively (see Table 5). A close analysis of these entries suggested that college freshmen provided a higher number of deep, thorough, and explicit journal segments than did high school students ($\chi 2 = 3.200$, $df = 1$, $p < .05$) when describing the design process.

Although findings of group differences were encouraging, in that they suggested growth in self-regulation across grade levels, differences in the quality of SRL (depth, thoroughness, explicitness) regarding the design process were also apparent within each group. For example, the excerpts below represent differences in TI apparent in writing samples among college freshmen:

"As I currently understand it, the design task is to create the arm so that it will rotate at least 90 degrees. The gripper also needs to be able to pick up and move a golf ball or pencil. Both of these parts of the robot must be able to attach to the slider on the provided part." (A deep, thorough, and explicit Task Interpretation of Design Process)

"My current understanding is that we are supposed to use the skills we've learned in solid edge, and apply them to creating a robotic arm." (A less deep, thorough, and explicit Task Interpretation of Design Process)

Similarly, the following excerpts from high school students illustrate differences in TI among students at this group:

"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 150ft x 125 ft and bet set back 6ft from the property line." (A deep, thorough, and explicit Task Interpretation of Design Process)

"My current understanding is that I have to achieve a way to complete the tasks of making a library well suited for the townsfolk." (A less deep, thorough, and explicit Task Interpretation of Design Process)

This finding of within-group variability is significant because it suggests that strengths, and gaps, in SRL were evident at both high school and college levels.

4.2. Task interpretation and reported strategy use while managing a design project

Self-regulated learning during project management was evaluated in two ways paralleling what was done when describing SRL during the design process. First, descriptions of the level and quality of SRL features were initially made for both groups of students. Then an analysis of patterns across SRL features was conducted to determine if potential gaps existed among SRL features for either or both groups. Since students in the Architectural Project were working individually, they were not required to complete EDQ survey items associated with project management. Thus, we only analyzed data for 21 of the high school students. Means and standard deviations for high school students and college freshmen are reported in Table 6.

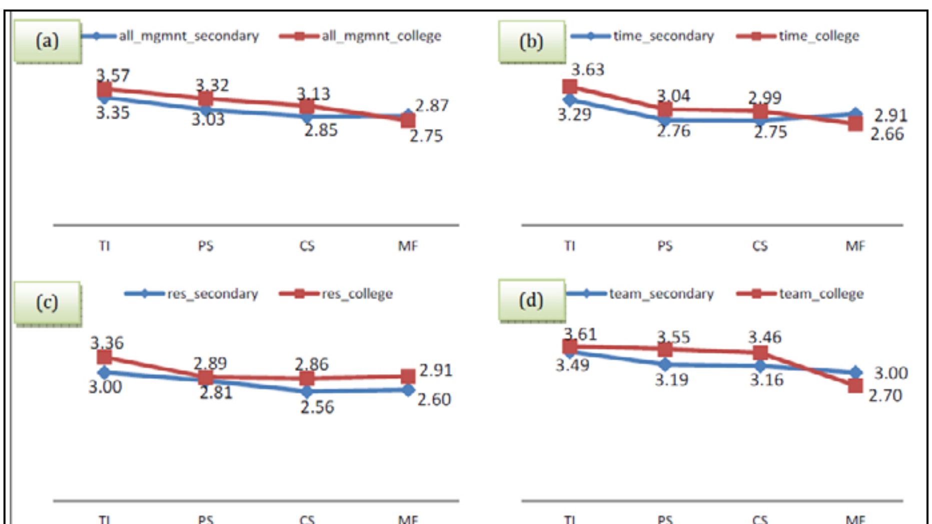

Figure 6. Design Management components across SRL features between high school and college freshmen: (a) all components, (b) time, (c) resources, and (d) teamwork

Analyses to evaluate students' SRL were conducted separately for three specific project management requirements, specifically managing time, resources, and teamwork. Findings indicated again that both college and high school students were focusing more on interpreting tasks than on reporting strategies for meeting task demands. For example, for project management overall the results revealed significant differences between *TI* and *PS* ($Z = -1.663$, $p < .05$), *TI* and *CS* ($Z = -2.918$, $p < .01$), and *TI* and *MF* ($Z = -2.745$, $p < .01$) for high school students. Considering specific aspects of project management, results indicated significant differences for these students between: (1) *TI* and *PS* on time ($Z = -1.979$, $p < .05$); (2) between *TI* and *CS* on time ($Z = -2.514$, $p < .01$), resources ($Z = -2.161$, $p < .05$), and teamwork ($Z = -1.918$, $p < .05$), and (3) between TI and MF on time ($Z = -1.921$, $p < .05$), resources ($Z = -2.126$, $p < .05$), and teamwork ($Z = -2.537$, $p < .01$).

Significant differences were also found for college freshmen on project management overall between *TI* and *PS* (Z = -4.012, $p < .001$), *TI* and *CS* (Z = -5.797, $p < .001$), and *TI* and *MF* (Z = -7.234, $p < .001$). On the project management component level, the results indicated significant differences for college students between: (1) *TI* and *PS* on time (Z = -4.916, $p < .001$) and resources (Z = -4.338, $p < .001$); (2) between TI and CS on time (Z = -5.498, $p < .001$) and resources (Z = -4.583, $p < .001$), and (3) between *TI* and *MF* on time (Z = -6.367, $p < .001$), resources (Z = -4.024, $p < .001$), and teamwork (Z = -7.202, $p < .001$).

Again, findings from the EDQ generally suggested greater levels of SRL for college-level students. Overall, college freshmen were more likely than high school students to report implementing plans by selecting appropriate cognitive strategies to accomplish tasks for managing a design project (see Table 6). The EDQ data also revealed higher scores for college freshmen in managing time (*TI*: Z = -2.232, $p < .05$), resources (*TI:* Z = -1.840, $p < .05$; *CS*: Z = -1.880, $p < .05$; *MF*: Z = -2.242, $p < .05$), and teamwork (*PS*: Z = -2.142, $p < .05$; *CS*: Z = -2.044, $p < .05$) (see Figure 6). In contrast, high school students reported higher levels of *MF* than did college-group peers, both when managing time (*MF*: Z = -2.209, $p < .05$) and teamwork (*MF*: Z = -3.085, $p < .01$).

Analysis of journal entries revealed important patterns in SRL for each group while managing the design project. College students described monitoring & fix-up strategies (138 segments – 37 percent) more often than they described issues related to task interpretation (41 segments – 11 percent), planning (96 segments – 25 percent), or cognitive (98 segments – 27 percent) strategies. For college students, Chi-square tests indicated significant differences between *MF* and *PS* ($\chi^2 = 7.538$, $p < .01$), *CS* ($\chi^2 = 6.780$, $p < .01$), and *TI* ($\chi^2 = 52.564$, $p < .001$). These data suggest that college students (on average) were engaged actively in monitoring performance and adjusting learning as needed.

In contrast, high school students' focus on cognitive strategies (10 comments – 67 percent) outpaced their mentioning of task interpretation (1 segment – 8 percent), planning (3 segments – 21 percent), and monitoring & fix-up strategies (1 segment – 8 percent). Chi-square tests for this group revealed significant differences between *CS* and *TI* ($\chi^2 = 7.364$, $p < .01$), *PS* ($\chi^2 = 3.769$, $p < .05$), and *MF* ($\chi^2 = 7.364$, $p < .01$). This pattern suggests that high school students were more focused on "doing the task" than they were on actively self-regulating performance (i.e., interpreting tasks, planning, or monitoring outcomes). Note, however, that reported patterns on high school students must be interpreted very cautiously given the low number of journal entries in which SRL features were mentioned.

Indeed, analyses of SRL as reflected in students' journal entries revealed much less attention to SRL by students at the high school level (see Table 7). Within journal entrees, college freshmen mentioned SRL-related features more often than their high school counterparts (i.e., college freshmen and high school students mentioned 5.33 and 0.48 segments/student, respectively; $\chi^2 = 5.000$, $df = 1$, $p < .05$). Further, college freshmen reported a higher number of deep, thorough, and explicit journal segments than did high school students ($\chi^2 = 4.000$, $df = 1$, $p < .05$) during project management.

Again, while expected differences in SRL as a function of educational level were observed in project management, journal entrees also revealed differences in the quality of SRL, as reflected in deep, thorough and explicit journal entries, within each of the student groups. To illustrate, the following excerpts present descriptions of cognitive strategies among college students during project management:

> *"My partner and I will each design one of the major beams. We will reconvene and determine how to fit them together and how to attach them to the frame of the robotic arm and to the pneumatic cylinders. We will then decide what to do next.* (A deep, thorough, and explicit Cognitive Strategies on Project Management –Teamwork)

> *"Divide up work. Meet with teammate. Start designing Air cylinders and refining overall design."* (A less deep, thorough, and explicit Cognitive Strategies on Project Management–Teamwork)

Similarly, design journal entrees revealed different levels of description among high school students:

> *"I am designing the robot in Solid Works, while may partner builds it. My friend is building the robot while I am designing so we won't fall behind."* (A deep, thorough, and explicit Cognitive Strategies of Project Management –Teamwork)

> *"We will also work together to work effectively."* (A less deep, thorough, and explicit Cognitive Strategies of Project Management –Teamwork)

5. Summary and Discussion

5.1. Summary

One main goal of this study was to describe SRL among high school students and college freshmen while engaged in an engineering design activity. As expected, we observed that college freshmen had better developed approaches to SRL than did their high school counterparts. In the overall design process, college students reported higher levels of self-regulation on the EDQ, in interpreting design tasks, planning, selecting strategies for task completion, and monitoring/ regulating approaches. Significant differences on reported use of cognitive strategies were also found at the sub-phase level, during problem definition (on design objectives and design constraints) and during conceptual design (on design functions and design alternatives). Moreover, during project management, college freshmen reported greater levels of self-regulation on all SRL strategies except for monitoring/ fix-up strategies while managing time, resources, and teamwork. Consistent with the EDQ data, in journal entries college freshmen provided a higher number of deep, thorough, and explicit descriptions of self-regulating activity than did high school students. This combination of

SRL Scores for High School Students and College Freshmen (Project Management)

SRL Feature	High school students (n = 21) *M (SD)*	College freshmen (n = 70) *M (SD)*
Task interpretation (*TI*)	3.35 (.57)	3.57 (.41)
Planning Strategies (*PS*)	3.03 (.71)	3.32 (.46)
Cognitive Strategies (*CS*)*	2.85 (.51)	3.13 (.45)
Monitoring/Fix-up Strategies (*MF*)	2.87 (.44)	2.75 (.35)

Note: * Significant at the .01 level (one-tailed)

Table 6

Journal Segment Quality across Groups (Project Management)

Groups / Quality of journal segments	High school students (∑ segments/student)	College freshmen (∑ segments/student)
Deep, thorough, explicit*	8/27 = .29	248/70 = 3.54
Narrow, less thorough, not explicit	5/27 = .19	125/70 = 1.79
Total segments/student	(8 + 5) / 27 = .48	(248 + 125) / 70 = 5.33

Note: * $p < .05$

Table 7

findings suggests that the level of SRL for college freshmen outpaced that of their counterparts at high school, and reveals important gaps in self-regulated performance for high school-level learners.

However, beyond these anticipated group differences, our findings also surfaced problematic patterns in SRL within and across both groups of students. For example, students at both levels placed more emphasis on task interpretation than they did on developing proper plans, selecting strategic actions to implement the plans, and monitoring all of their SRL features to complete the design task. These findings suggest that both high school students and college freshmen have relatively good awareness of task demands, but lack awareness of how to translate that understanding into proper plans and plan execution. These challenges were found both in the design process and project management. Furthermore, we found important within-group differences in the quality of self-regulation at both the high school and college levels. This latter finding, reflected in differences in the depth, thoroughness, and explicitness of journal entries, suggests important gaps for some learners in both college and high school classrooms that need to be addressed through effective instruction.

5.2. Discussion

The findings of this study are important in terms of advancing understanding about SRL for both high school and college students. Complexity in engineering design activities requires SRL skills to monitor goals in learning or solving problems. However, findings from prior research have suggested that high school students and college freshmen are challenged to engage effectively in SRL when presented with engineering design activities. For example, another study in a university context revealed that engineering college freshmen reported low awareness of self-regulated strategies (e.g., Froyd et. al., 2005). In our prior work, we have also found that, although students had a good understanding of design tasks, they experienced difficulties in translating their understanding into plans (Lawanto, 2011; Lawanto, Butler, Cartier, Santoso, Lawanto, & Clark, 2012; Lawanto, Goodridge, & Santoso, 2011). This study extends prior research by examining high school and college students simultaneously, employing a common analytic framework. Contributions of the current research are elaborated within three subsections as follows:

5.2.1. Advancing understanding about how task interpretation is related to reported strategy use during the design process and management

A particular contribution of this study is the finding of gaps between task interpretation and strategic performance for learners at both high school and college levels. Consistent with our prior research, pattern analysis of SRL features revealed significant differences between task interpretation and SRL strategies for both groups, not only during the design process but also on project management components. These findings suggest that, in this study, students at high school and college levels were similarly challenged to translate task understanding into effective, self-regulating approaches to learning. This is potentially problematic because task interpretation is so important for successful performance (e.g., Butler & Winne, 1995; Butler & Cartier, 2004).

As expected, we also found that college freshmen outperformed high school students in almost all SRL features during the design process. Group comparisons should be interpreted with caution, because the contexts in which students were working varied significantly across levels (e.g., in terms of task demands and difficulty). Nonetheless, this finding is encouraging in that it suggests that more senior, experienced students were more adept at managing their engagement in design tasks, at least across the contexts examined in this work. This is consistent with prior research showing that during engineering design activity, senior students were more active than freshmen students in making transition between steps (Atman, Chimka, Bursic, & Nachtmann, 1999). However, a key finding was that there were gaps in self-regulation for groups at both levels. Thus, while college students may have outperformed their younger counterparts on average, strengths and challenges in engineering design performance were apparent at both educational levels.

5.2.2. Field-testing a methodological framework for identifying patterns in students' SRL while solving a design problem

Another contribution of this study was to continue field-testing methodological tools for studying SRL as situated in design activity, as has been called for in the literature (e.g., Butler, 2011; Winne & Perry, 2000). To that end, two sources of data were collected to capture students' SRL: a survey instrument and Web-based design journal entries. Descriptive statistics, non-parametric statistics, and graphical views were used to analyze survey responses. Entries from students' design journals were segmented and coded using an SRL model and interpreted to triangulate and complement survey data to achieve better insight about the employed strategies of these two groups.

The findings reported here suggest the heuristic value of the methodological framework employed for researching SRL as it unfolded in two very different contexts, across educational levels. Tracing self-regulation over time through the design activity using a combination of tools allowed us to ascertain patterns that held "on average" within and across groups, and to uncover qualitative differences in self-regulated performance both between and within groups. This framework provides the community with a tool in assessing similar data in similar studies.

5.2.3. Developing awareness about SRL practices to curriculum developers and engineering design teachers

This research will not only advance understanding about metacognition and SRL as implicated in design activities at both first-year college and high school levels, but it also generates implications about how to support students' development of knowledge concerning themselves as learners and spur change at associated schools. Metacognition and SRL have been shown to be key factors in effective performance. While it is encouraging that college freshmen were better than high school students, there is still a need to foster positive SRL for the more mature learner. In fact this study provides evidence that SRL instruction should be present at both high school and college levels. For high school students, it is clear that students need support in interpreting task demands and identifying planning strategies. They also need support regarding the use of effective strategies to work through design processes as well as strategies involving monitoring/fixing up their work. Emphasis in these areas of SRL instruction will increase success in high school courses, and elevate students to the level demanded at the next stages of their education. The data indicates that college students also need support to more effectively translate understandings of task demands into effective planning and strategy use. There are different approaches recommended in the literature that might achieve these goals, including explicit instruction, modeling, directed reflection (see Boekaerts & Corno, 2005; Paris & Winograd, 1999), and the use of standardized diaries (Schmitz & Wiese, 2006). Examining the benefits of these approaches to advancing SRL should be the subject of future research.

In conclusion, the research reported here builds from prior research to advance understanding about strengths and challenges in SRL during design activity and project management for high school and first-year college students. To build further from these efforts, we offer three recommendations. *First*, an increase in the sample size is essential to improve the generalizability of the findings. Recruitment of several colleges and schools is necessary to elicit more diverse contexts in understanding students' SRL. *Second*, future study is needed to continue to nuance questionnaire statements and journal prompts to match the task demands placed on high school and college group students. As suggested by Vanno, Lai, Jin, and Link (2011), questionnaire design improvement efforts (e.g., instructions, wording) can potentially enhance the quality of data collected. In our case, because of some technical terminologies included as parts of statements in the questionnaire, students may engage in metacognitive strategies while solving the design tasks and not reporting the strategies when responding to the questionnaire. *Third*, prior research suggests the importance of extending research to investigate gender differences in use of metacognitive strategies when solving ill-structured problems (Leutwyler, 2009; Schiefele, Streblow, Ermgassen, & Moschner, 2003).

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grants No. 1148806 and 0426421. Any opinions, findings, and conclusions or recommendations expresses in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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