An Exploratory Study of Self-Regulated Learning Strategies in a Design Project by Students in Grades 9-12

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Abstract
This exploratory study evaluated self-regulated learning (SRL) strategies of 27 students in grades 9-12 during an engineering design project. The specific focus of the study was on student task interpretation and its relation to planning and cognitive strategies in design activities. Two research questions guided the study: (1) To what degree was students' task interpretation reflected in their working plans and SRL strategies use across the design process?; and (2) How did relatively lower- and higher-achieving design-performing students differ in interpreting tasks and deploying SRL strategies? Survey instruments and Web-based design notebook writing were used to capture students' reported use of SRL strategies. On the survey, students reported use of SRL strategies at the early, middle, and final stages of the design task, with a focus on task interpretation, planning, cognitive, monitoring/fix-up strategies, and performance criteria.

The findings suggested that students scored higher on task interpretation than on planning, cognitive, and monitoring/fix-up strategies. Students' relatively high awareness of task interpretation-related-issues was also reflected in what they considered to be good design performance. Our findings were suggestive that higher performing students scored significantly higher than their lower-performing peer on cognitive and monitoring and fix-up strategies. On the other hand, lower-performing students reported greater use of planning strategies. Moreover, higher-performing students seemed to be able to convey more detailed and specific descriptions than did their relatively-lower performing peers. This article discusses potential implications for design instruction in grades 9-12.

Key words
design, grades 9-12, metacognition, self-regulated learning

Introduction
There is a widely accepted theory among Science, Technology, Engineering, and Mathematics (STEM) educators that teaching concepts and skills in the context of solving engineering design-type problems will enable students to more easily grasp and retain those concepts (Katehi et al, 2009). Although there is a strong push among educators to emphasise engineering design in K-12 engineering education either in Australia, Europe, or United States (Eder, 1993; Göl et al, 2004; Katehi et al, 2009), few studies have assessed how students' self-regulated learning (SRL) strategies are selected and deployed to solve complex problems (De Corte et al, 2011). Having a better understanding about those strategies is essential, however, because consistency in employing SRL strategies is highly correlated with student achievement (Zimmerman and Schunk, 2011), particularly in the kinds of complex, ill-structured tasks so ubiquitous in Engineering education and practice.

SRL can be defined essentially as a form of iterative, goal-directed activity that involves interpreting tasks, setting goals, selecting, adapting or even inventing strategies effective for achieving those goals, monitoring progress, and adjusting approaches as needed (Zimmerman, 2008). Effective SRL is invited by and particularly critical in complex or ill-structured tasks, such as engineering design (Lawanto, 2010; Lawanto and Johnson, 2012). As stated by Dym and Little, "Designing is about people planning and creating ways to produce things that achieve some known goals" (2009: 5). The design process is not linear; at any phase of the process, students must identify, plan, act, evaluate, and make necessary adjustments. Students' development of SRL strategies is particularly essential when working on ill-structured problems such as engineering design tasks that are more difficult to solve and require more cognitive operations than do well-structured ones (Paris and Winograd, 1990).

As an illustration, when working on a design project such as designing and building a robot that can move soda cans from one place to another or a new library that has a full-service facility, students are expected to correctly interpret task requirements before formulating strategic plans to achieve them. These plans are expected to identify focused cognitive strategies necessary to project completion. Students are then expected to enact those strategies, monitor progress, and adjust approaches in order to achieve important criteria as suggested by design problems. In this research, we examined how students engaged in these cycles of SRL in the context of these two design activities.

More specifically, Butler (1998) found that having a good understanding of a presented learning activity grounded in productive metacognitive knowledge about tasks is essential to students' successful planning, self-monitoring, and selection of appropriate strategies to accomplish task objectives (see also Butler and Cartier, 2004b). Thus, in this research, we focused specifically on evaluating how students' understanding about a design task might be reflected in planning, cognitive actions, and monitoring and fix-up strategies to solve and enhance design processes and outcomes.

Relevant literature review

Insights into metacognition in a self-regulated learning context

What is metacognition? In simple language, metacognition refers to thinking about thinking (Brown, 1987). While the term *cognition* refers to one's ability to build knowledge and involves information processing, knowledge acquisition, and problem solving, the term *metacognition* refers to both understanding about and control of that working cognition (Flavell, 1979; Gourgey, 1998). Scholars define metacognition in numerous ways, many of which overlap; however, most definitions identify as metacognitive as comprising two main components: (1) metacognitive knowledge and (2) metacognitive control. For example, informed by the classical theories of metacognition introduced by Flavell (1976), Pintrich (2002) described metacognition as involving both knowledge and control. Students hold metacognitive knowledge about strategies that might be used for a particular task and the conditions under which the strategies might be useful. Metacognitive control encompasses processes that learners use to monitor and self-regulate cognition and learning.

While many theoretical perspectives on metacognition and self-regulation have been offered (e.g., Butler and Winne, 1995; Winne and Hadwin, 1998; Zimmerman, 2002; Zimmerman and Schunk, 2001), for this research we chose to build from Butler and Cartier's socio-constructivist model of self-regulation (Butler and Cartier, 2004a; Butler and Cartier, 2005; Cartier and Butler, 2004) because it enables teasing apart and investigating the interplay between metacognitive knowledge (e.g., students' understandings about tasks and strategies, as mediating variables), and metacognitive control, conceptualised as cycles of "self-regulation in action," within the context of complex learning activity. This model depicts eight central features that interact with each other to shape engagement in learning: layers of context, what individuals bring, mediating variables, task interpretation, personal objectives, SRL processes, cognitive strategies, and performance criteria.

First, layers of context refer to the learning environments, such as school, classroom, and instructional approaches, in which students engage in learning. In this project we attend to contextual influences by recognising how our study of SRL was situated in a particular kind of activity, during which students were engaged in an engineering design project together in particular projects and classrooms. Second, students bring to those contexts strengths, challenges, and interests that shape their engagement (e.g., by influencing whether they perceive activities to be difficult/easy or boring/important). Third, examples of variables that mediate student engagement in a learning task include students' conceptions of academic work, derived through prior experience (e.g., about learning in STEM as about memorising facts from textbooks), metacognitive knowledge (e.g., about tasks, strategies, learning), self-perceptions (e.g., of competence and control over outcomes) and emotions. In this project, because of our more targeted focus, we did not assess directly individuals' histories or a full set of potential mediating variables, as has been conducted in other research (e.g., Butler et al, 2011). However, through our attention to task interpretation, we created the opportunity to infer how students' prior experiences may have influenced their conceptions about learning in engineering, and the metacognitive knowledge they may have constructed related to design tasks.

Our focus in this project is more specifically on the fourth component of the Butler and Cartier model, task interpretation, and its relationship to students' use of cognitive and self-regulating strategies. Task interpretation is the heart of the SRL model inasmuch as it shapes key dynamic and recursive self-regulating processes (Butler and Winne, 1995). 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. When students self-regulate learning effectively, task interpretation and personal objectives, the fifth feature of the Butler and Cartier model, work together to inspire students' activation of effective self-regulating and cognitive strategies during a design task.

Sixth, in light of their task interpretations and personal objectives, students manage engagement in academic work by using a variety of self-regulating strategies:

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planning, monitoring, evaluating, and adjusting approaches to learning. Ideally 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.

A seventh feature of the Butler and Cartier model is that they situate students' use of cognitive strategies in the context of cycles of dynamic, iterative self-regulating activities. Students with good metacognitive skills and awareness use these processes to oversee their learning process (e.g., to plan and monitor ongoing cognitive activities). Finally, as part of that monitoring effort and, in an on-going way, students compare outcomes that emerge through their activity (process, cognitive) with internal or external standards (Flavell, 1979). Linked to task interpretation and personal goals, performance criteria are the standards against which students judge the progress they are making (see also Butler and Winne, 1995).

Zimmerman and Pons (1986) found that consistency in employing self-regulated learning strategies is highly correlated with student achievement. Schoenfeld (1983) argued that lack of success in problem-solving may result from the absence of assessments and strategic decisions. Thus, students with poor metacognition (knowledge and control) may benefit from training to improve metacognition and subsequent learning performance (Coutinho, 2008). When students engage in complex and ill-structured problem-solving (as in design tasks), these SRL features dynamically interact. Thus, in this study our goal was to document the dynamic interconnections between students' interpretation of design tasks, self-regulating and cognitive strategies, and criteria students associate with success.

Note that, while models of "self"-regulation focus on how individuals engage in iterative cycles of adaptive learning activity, many researchers also describe how self-regulation is mediated socially (e.g., Bandura, 2006; Vygotsky, 1978). Thus, when peers learn together, as is frequently the case within design projects, forms of co-regulation may emerge, where students shape and scaffold each other's engagement (e.g., see Hadwin and Järvelä, 2011; Volet, Summers, and Thurman, 2009). In this research, an important contextual influence was that students were engaged in design activities together.

Engineering design process

Design problems are among the most complex and ill-structured tasks encountered in engineering practice (Jonassen, 2000; Reitman, 1965; Simon, 1973). For many years, researchers (Reitman, 1965; Simon, 1973) have characterised design problems as ill-structured because they have ambiguous specification of goals, no determined solution path, and require the integration of multiple knowledge domains. Goel and Pirolli (1989) articulated the characteristics of design problems, including many degrees of freedom in the problem statement, which consists only of goals and intentions, limited or delayed feedback from the world, artifacts as outputs that must function independently of the designer, and "answers that tend to be neither right nor wrong, only better or worse" (Jonassen, 2000: 80).

Solving an engineering design problem is a structured and staged process. In a model similar to those proposed by Christiaans (1992) and Cross (2000), Dym and Little (2009) contend that the design process consists of five phases: problem definition, conceptual design, preliminary design, detailed design, and design communication. 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.

In this study, we focused on the first two of Dym and Little's five design phases: *problem definition* and *conceptual design*. These two phases were selected because students' success in understanding the objectives of the project and how to conceptually solve a design problem has a significant impact on the remaining three design phases. Dym and Little (2009) divided these two phases into several sub-phases that we draw on in our analyses. The problem definition phase consists of four sub-phases: clarifying objectives, establishing metrics for objectives, identifying constraints, and revising a client's problem statement. In this study, students were working on an assigned task as part of the course requirement, with no option to change or revise the task. As a result, we attended only to the first three of these problem definition sub-phases. The second phase, conceptual design, involves six sub-phases: establishing functions, defining requirements, establishing means for functions, generating design alternatives, refining and applying metrics to design alternatives, and choosing a design solution.

Findings from previous studies suggested that metacognitive skills are essential in solving engineering design project because of the nature and complexity of the design processes (e.g., Lawanto, 2010; Lawanto and Johnson, 2012). The ways in which students use strategies, observe what transpires, and search for alternative solutions are examples of how metacognition is applied during these phases of the design process.

The Study

Overview

A central goal of this study was to describe the task interpretation of students engaged in a design activity and determine the extent to which they translated their understanding of the design task into planning and cognitive strategies. Two research questions guided this exploratory study: (1) To what degree was students' interpretation of the design task reflected in working plans and selected cognitive strategies across design process?; and (2) How did lower- and higher-design-performing students differ in interpreting tasks and deploying SRL strategies?

Study participants

A purposeful sampling strategy (Creswell, 2003) was employed for this study. One school in Colorado was selected because of its comprehensive set of engineering/technology-related courses. All students enrolled in both Architectural and Robotics Designs classes were invited to participate. Twenty-nine students, age ranged between 15 and 18, participated in the study: seven students (five females and two males) were in the Architectural Design class and 22 students (three females and 19 males) were in the Robotics Design class.

The context of the design tasks

Students enrolled in both design classes met four times a week, taught by the same teacher, and none of the students was enrolled in both classes. They were given a design task to work on as their final design project. They had three weeks to complete their project. Grades were assigned for their project and were counted towards each student's overall course grade. Students' grades used in this study reflected individual design performance. The requirements of the design projects were created by the teacher. A brief description of these two final projects is presented below.

Robotic design

Students were required to work in a team of two or three to design and build a robot capable of operating under a tele-operated mode, inside a 122 cm x 244 cm table with 5 cm high walls populated with eight empty soda cans. The cans were painted and divided into two colours, red and blue. Four of the cans (two blue and two red) sat atop pedestals, 15 cm high, positioned in each corner. Students were then required to swap the positions of the cans. Cans sitting on the pedestals were lowered and replaced with a can which had been sitting on the table surface. Students were given two and a half minutes to complete as many exchanges as possible. Students were required to fully design their robots, including drive train and actuator, using SolidWorks™ before building and competing in four matches. Grading criteria took into account both group and individual performance, and were established based upon the SolidWorks™ model, robot performance, team participation, and design journal writings.

Architectural design

Architectural design students designed and built a miniature of a new library to be built in a small town with a population of 25,000. As in the robotic design project, the architectural design students were required to undertake this task as their final design project. The library was to be built on a square corner lot measuring 150' x 150,' needed to include various facilities such as meeting rooms, performance space, a computer access area, an outside garden or reflection area with benches, a circulation desk, a staff office or break space, and

Figure 1. Activity and design artifact example in robotics design class

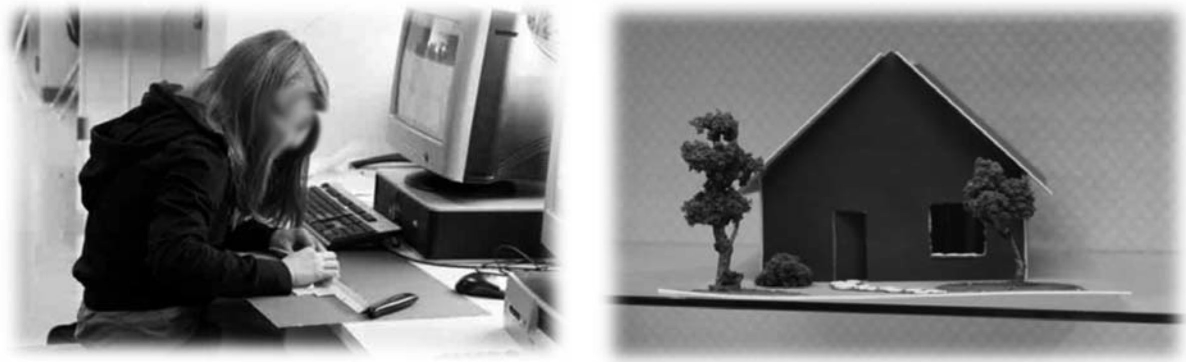

Figure 2. Activity and design artifact example in architectural design class

restrooms, and was required to be handicap accessible. Although the architecture challenge was individual, natural groupings of students formed and collaboration in terms of providing assistance to one another developed.

Data collection and analysis

In this study, data were collected through two sources: a self-regulated survey for engineering design (EDQ) and a Web-based engineering design notebook (WEDN). The survey questionnaire was used to capture students' task interpretation, perceptions about their planning, cognitive, and self-regulating strategies, and information about criteria they applied in assessing their own performance. Data on task interpretation and use of planning, cognitive and self-regulating strategies were also collected through the WEDN. Here students were asked to report their activities on projects twice each week using a Moodle-based application. Data collected from the design notebook were instrumental in triangulating and complementing survey data.

Data from the survey were collected at early, middle, and final stages of the design project through an online survey tool, in direct reference to the design task assigned by the teacher. In the early stage, the survey assessed students' task interpretation and planning strategies. In the middle stage, the survey assessed their cognitive and monitoring/fix-up strategies. In the final stage, the survey assessed criteria student used in their judgment of design outcomes. The questionnaire was adapted from the Inquiry Learning Questionnaire, which had been validated in prior research (Butler and Cartier, 2004; Cartier and Butler, 2004; see also Nomme et al, 2012). Measurement scales of the survey ranged from 1 to 4 (i.e., 1 = *almost never*, 2 = *sometimes*, 3 = *often*, and 4 = *almost always*). The students completed the survey at those three different stages of the project in class and it was administered by the teacher (see table 1 for a sample of the survey items).

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 get a good overview of the design objectives.
Planning Strategies	Before I begin to work on the design task, I list ways to identify design objectives.
Cognitive Strategies	When working on this kind of design task, I read the design description (or brief).
Monitoring and Fix Up	During my work on my design task, I look back at the design description (or brief).
Criteria for Performance	At the end of this design task, I know that I have done a good job when I evaluate whether a good understanding of the design objectives was achieved.

Table 1. SRL features and examples in the context of defining the design project

Dimensions	# of items	Cronbach's Alpha
Task Interpretation	9	.80
Planning Strategies	9	.77
Monitoring & Fix Up	20	.91
Cognitive Strategies	25	.91
Performance Criteria	9	.88

Table 2. Internal reliability scores

The EDQ was developed and pilot-tested in previous research (Lawanto, 2011, Lawanto et al, 2011) to capture the relationships among the main features of the SRL model for secondary and postsecondary students engaged in design project. An exploratory factor analysis was conducted to identify the internal reliability of EDQ constructs. Table 2 shows that dimensions targeted in this study had very high Cronbach's Alpha scores.

Before analysing data, collected surveys were first evaluated for irregularities. There were two suspiciously completed surveys that required us to further investigate the validity of the responses. As a result of those findings, we excluded the two surveys from our data pool and, therefore, ended up with 27 surveys to be analysed. The analysis process involved evaluating both quantitative and qualitative data. Quantitative data collected from the survey were analysed by first calculating the mean values of the SRL features and then comparing them across the two design phases and nine sub-phases. Due to the small sample size, non-parametric tests were conducted in this study. Second, relationships between SRL features across time were represented in graphical views so that student SRL profiles across the design process could be visually compared. Transitions across items were considered using an item mapping analysis that explored the relationship of items across SRL features.

Qualitative data collected from students' design journals were first categorised according to the SRL features and then coded using Dym and Little's (2009) conceptual model. This approach allowed us to identify how SRL features were identified within design phases and sub-phases. Two research assistants segmented and coded the quality and SRL features reflected in students' journal entries to ensure consistency of segmenting and coding. Inter-rater reliability was at acceptable levels (98% agreement), and any disagreements between raters were reconciled before calculating final frequencies.

Findings

Research Question 1: To what degree was students' interpretation of the design task reflected in working plans and SRL strategies use across the design process?

To address this question, we first focused attention on the design process as a whole. Across time, while engaged in their respective design tasks, students reported on their engagement in SRL, from interpreting tasks *(TI)*, to use of planning *(PS)*, cognitive *(CS)* and monitoring/fix-up *(MFS)* strategies, to applying criteria to evaluate their final performance *(CR)*. Our initial analyses considered the relationships between overall mean scores among these different features of self-regulation and cognition.

From the survey, the findings suggest that, on average, students scored higher on task interpretation than on their use of strategies. Students were aware of the need to identify what they needed to do (M=3.13, SD=.44). But they were less likely to report using strategies for planning (M=2.76, SD=.61), completing design tasks (M=2.72, SD=.34) or monitoring progress and repairing problems (M=2.84, SD=.42). A series of Wilcoxon tests was conducted to evaluate whether these gaps between SRL features were significant. The results indicated significant differences between task interpretation and planning strategies (Z=-2.91, $p < .01$), task interpretation and monitoring/fix-up strategies (Z=-2.395, $p < .05$), and cognitive and monitoring/fix-up strategies (Z=-2.223, $p < .05$). This finding was consonant with the reports of self-regulation evident in student notebooks. Here qualitative coding revealed many more entries focused on task-interpretation (100 segments), than on considering or using planning (63 segments), cognitive (56 segments), or monitoring/fix-up (72 segments) strategies. Note that, as will be described in more detail below, on the survey, students' relatively high sensitivity to task interpretation was also reflected in relatively high scores on performance criteria, which indicated what they considered to be a good design performance.

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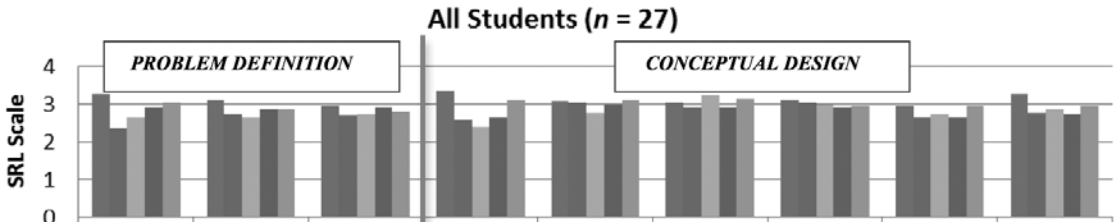
Problem Definition (pdf)

In a more detailed set of analyses, we analysed data to track how SRL unfolded across the problem definition and conceptual design phases separately. A detailed report of SRL mean scores within each phase, and associated sub-phases, is provided in figure 3. To aid in analysis, we interpreted scores on any SRL feature as *low-to-moderate* if they fell between 1.00 and 2.75 on the four-point scale, and as *moderate-to-high* if they fell between 2.76 and 4.00.

Findings here suggest that, across sub-phases of Problem Definition, students had *moderate-to-high* awareness of design issues required to understand the task *(TI)*. Although students had lower scores on performance criteria *(CR)* than *TI* in all three sub-phases of the problem definition phase, they nonetheless showed *moderate-to-high* awareness on *CR*. In particular, students indicated that getting a good grasp of the design objectives constituted an important criterion in judging design success (*M*=3.04, *SD*=.65).

However, students' awareness of task requirements (reflected in *TI* and *CR*) was not well reflected in planning strategies. For example, despite the students' *moderate-to-high* awareness of the need to get a good overview of design objectives (*M*=3.26, *SD*=.71), they did not as frequently report using planning strategies focused on identifying what those design objectives were (*M*=2.37, *SD*=.74). Results of Wilcoxon tests for Problem Definition indicated a significant difference between task interpretation and planning strategies on design objectives (Z=-3.624, p < .01). Although not statistically reliable, similar trends were observed for the other two sub-phases in problem definition. Specifically, while students showed a *moderate-to-high* awareness of considerations in interpreting the task in relation to design metrics and constraints (*M*=3.11 and *M*=2.96, respectively), their reported engagement in planning strategies in those sub-phases were at a *low-to-moderate* level (*M*=2.74 and *M*=2.70, respectively). These findings suggest that supporting students to be aware of and engage in planning to identify design objectives, measures, and constraints could help them to achieve a better, more holistic understanding of a design task.

When considering how students approached clarifying design objectives, differences were also observed between levels of planning reported (*M*=2.37, *SD*=.74)



	dob	dme	dcon	dfunc	dreq	dmea	dalt	dmr	dsel
TI	3.26	3.11	2.96	3.37	3.07	3.04	3.11	2.96	3.26
PS	2.37	2.74	2.7	2.59	3.04	2.93	3.04	2.63	2.78
CS	2.64	2.63	2.72	2.39	2.76	3.22	2.98	2.74	2.85
MF	2.91	2.85	2.93	2.65	2.98	2.91	2.91	2.63	2.74
CR	3.04	2.85	2.81	3.11	3.11	3.15	2.96	2.96	2.96

Features of SRL: TI: Task Interpretation; ***PS:*** Planning Strategies; ***CS:*** Cognitive Strategies; ***MFS:*** Monitoring/Fix-Up Strategies; ***CR:*** Criteria for Performance

Design Phases and Sub-Phases: **(1) Problem Definition: dob:** clarifying design objectives; ***dme:*** establishing design metrics; **dcon:** identifying design constraints; **(2) Conceptual Design: dfunc:** Establishing design functions; ***dreq:*** Establishing design requirements; ***dmea:*** Establishing design means; **dalt:** Generating design alternatives; **dmr:** Refining design metrics; **dsel:** Choosing design solutions.

Figure 3. Comparison of SRL features mean values across design sub-phases for all students

and reported use of cognitive and monitoring/fix-up strategies (M=2.64, SD=.56 and M=2.91, SD=.55, respectively). While there were significant differences between planning strategies and cognitive strategies (Z=-2.559, p < .05) and between planning and monitoring strategies (Z=-2.348, p < .05), no significant difference was found between cognitive strategies and monitoring/fix-up strategies and between task interpretation and performance criteria.

Conceptual Design (cd)

As we observed during Problem Definition, in the Conceptual Design phase students also exhibited *moderate-to-high* awareness related to task interpretation (with *TI* means ranging from 2.96 to 3.37 across sub-phases) (see figure 3). In general, students also showed *moderate-to-high* awareness of important criteria for judging performance (with *CR* means ranging from 2.96 to 3.11), a finding aligned with the students' high *TI*.

In this phase, students also reported *moderate-to-high* levels of planning when establishing design requirements (M=3.04, SD=.81) and means (M=2.93, SD=.83), generating alternatives (M=3.04, SD=.81), and choosing design solutions (M=2.78, SD=.97). That said, as during Problem Definition, we still observed important gaps between students' task interpretation and planning. First, while students exhibited moderate-to-high awareness of the importance of interpreting tasks to establish design functions (M=3.37, SD=.69), they less frequently reported use of good planning strategies to elaborate understanding of design goals (M=2.59, SD=.75). Results of Wilcoxon tests for Conceptual Design indicated a significant difference between task interpretation and planning strategies on design functions (Z=-3.377, p < .01). For example, students were well aware of the need to understand the action or function for which their design must perform, but failed to recognise the need to identify the input and output components needed to be incorporated into the design. Second, students' scores suggested *moderate-to-high* awareness of the need to narrow down and apply a refined set of measures that contribute to good design performance (M=2.96, SD=.71), but they appeared to be less aware of the benefit of planning to achieve that goal (M=2.63, SD=.84), as illustrated by their predilection to identify the measures before establishing a refined standard measurement. While this trend was suggestive, no significant difference was found between task interpretation and planning strategies on design metrics refinement.

As for the other SRL features, we observed a range in students' reported use of cognitive strategies associated with Conceptual Design, from a low when identifying design functions (M=2.39, SD=.59) to a high when establishing design means (M=3.22, SD=.80). These findings suggest that students failed to recognise important cognitive strategies applicable in certain sub-phases. Further, we observed a more consistent lower reporting of engagement in monitoring and fix-up strategies across most sub-phases, particularly in comparison to scores on task interpretation. For example, compared to a task interpretation mean of 3.37, when establishing design functions students' reported use of monitoring and fix-up strategies was much lower (e.g., M=2.65, SD=.62). Similar gaps between monitoring/fix-up strategies and task interpretation were found in design selection (i.e., M=2.74, SD=.61; M=3.26, SD=.81, respectively). Results of Wilcoxon tests indicated significant differences between task interpretation and monitoring/fix-up strategies on design functions (Z=-3.108, p < .01) and on design selection (Z=-2.458, p < .05).

Research question 2: How do low- and high-design-performing students differ in interpreting and deploying SRL strategies?

Project grades for students were reported by their teacher, and were used to cluster students into groups of relatively lower and higher performers. Note that, while project grades did take into account a group's achievement, they also reflected individual differences (e.g., as reflected in students' accounts in design notebooks). Overall the mean grade across all participating students was 91.07% (SD=4.62), which was relatively high. However, we were able to identify relatively higher-performing students as those whose scores were at least ¾ of an SD above this mean (scores ≥ 94.5; n = 12), and relatively lower-performing students as those whose scores were at least ¾ of an SD below the mean (scores ≤ 87.6; n = 7). By employing .75 SD, we could meaningfully differentiate the level of design performance and also have enough sample size for the two groups.

To address the research question, we first calculated and compared mean scores and significance differences of SRL strategies between higher- and lower-performing students. Table 3 reports our findings from the survey comparing mean scores across the entire design project for the two groups of students. What can be observed here is that overall mean scores were essentially equivalent across groups for task interpretation and reported use of cognitive and monitoring-fix up strategies. While not statistically reliable, a surprising trend was observed from the lower-performing students who

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SRL Feature	Higher-performing students M (SD)	Lower-performing students M (SD)
Task interpretation	3.10 (.44)	3.03 (.52)
Planning Strategies	2.56 (.61)	2.81 (.48)
Cognitive Strategies	2.80 (.34)	2.71 (.24)
Monitoring/Fix-up Strategies	2.96 (.42)	2.93 (.14)
Criteria for Performance	2.96 (.39)	3.14 (.44)

Table 3. Comparison of SRL scores for higher- and lower-performing students (N=19)

reported greater use of planning strategies. Although there was no significant SRL difference found between both groups of students at the design phase level, Mann-Whitney tests revealed significant differences in design sub-phases across SRL strategies using one-tailed *p*-values ($p < .05$). Specifically, we found that higher performing students scored significantly higher than their lower-performing peer on selecting strategies to establish design means and monitoring/fix-up strategies to generate design alternatives. We also found lower-performing students scored significantly higher on planning their design metrics refinement than their high-performing peers. Tentative interpretation of this result suggests that, while lower-performing students may have been more active in planning, they were not more likely to translate those plans into action.

While differences between higher- and lower-performing students were not as pronounced in the survey findings, analysis of notebook writings did reveal important differences across the two groups. First, on average, higher-performing students mentioned SRL-related features more often in notebooks than did their lower-performing peers (i.e., 15 vs. 11 total segments per student, respectively). We found from Chi-square test conducted that the difference of the total number of segments per student between both groups was significant ($\chi^2 = 4.154$, df = 1, p = .02). Second, higher-performing students conveyed more detailed and specific descriptions of task requirements and strategies enacted than did their relatively-lower performing peers. Table 4 shows the distribution of segment quality between higher- and lower-performing students found from their design notebooks. Again, Chi-square tests indicated that the differences between both groups in terms of the detailed and specific journal entries are significant ($\chi^2 = 7.686$, df = 1, p = .006) and the less detailed and less specific entries are also significant ($\chi^2 = 8.000$, df = 1, p = .005).

For example, while both groups may have been relatively well aware of the importance of task interpretation according to survey results, the qualitative results from the notebooks show that higher-performing students described their understanding of the tasks in greater detail than did lower-performers. Consider, for example, the four excerpts below that were drawn from the writing samples on task interpretation of higher- and lower-performing students, a pair each for robotic and architectural design contexts:

> 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 lots that is 150ft x 125ft and be set back 6ft from the property line. *(Higher-performing Architectural student)*
>
> I understand that I have to build a library for a small town of 25,000 thousand. *(Lower-performing Architectural student)*

Groups Quality of journal report segment	Higher-performing students (Σ segments/student)	Lower-performing students (Σ segments/student)
Detailed and specific	115/12 = 9.58 (65%)	28/7 = 4.86 (37%)
Less detailed and specific	61/12 = 5.08 (35%)	48/7 = 6.86 (63%)

Table 4. Comparison of journal report quality across groups

> We will be designing robots that can knock off cans from a pedestal, standing up right, and put cans from the table on top of the pedestal. *(Higher-performing Robotic student)*
>
> That we have to pick up cups or knock them off a table, and gain points for doing it. *(Lower-performing Robotic student)*

Thus, although both higher- and lower-performing students identified the design requirements for their projects, it was clear from the above-referenced excerpts that the higher performers were more thorough in identifying and describing essential design specifications for their projects than were the low performers.

Similarly, while overall survey mean scores may have been similar for monitoring and fix-up strategies across the two groups, important differences in the quality of strategy use were revealed in the analysis of notebook entries, as noted in the following excerpts:

> I mapped out exactly where I want everything to go, now I need to think about what they dimensions are going to look like. It is going to be some though work, but I know I can do it. I think I need to improve on making the window dimensions more accurate. *(Higher-performing Architectural student)*
>
> I am struggling with find the right measurement for each of the rooms. *(Lower-performing Architectural student)*
>
> Today we finalised the elevator for our robot and we figured out a way to put the string on the robot, but our claw design is pretty flawed and is very flimsy. *(Higher-performing Robotic student)*
>
> Got farther on the design and built of the robot. *(Lower-performing Robotics student)*

But, while we found group differences in the quality of self-regulation between lower- and higher-achieving students, as described above, survey data revealed similar gaps between task interpretation and reported use of strategies for both groups of students. Inspection of means suggested that higher achievers were relatively high on task interpretation, compared to lower scores for planning, cognitive and monitoring/fix-up strategies (see table 3); however, significant differences (p <.05) were found only between task interpretation and planning and task interpretation and cognitive strategies. A similar trend was apparent for lower-achieving students, where task interpretation was significantly higher than were reports of planning and use of cognitive strategies (p <.05). Similarly, notebook data showed that, consistent with earlier analyses, both higher- and lower-performing students focused more on task interpretation than they did on describing and implementing strategies. Higher-performers described task-interpretation-related issues more often (62 segments) than they described issues related to planning (28 segments), cognitive (46 segments), or monitoring and fix-up (40 segments) strategies. Similarly, low-performing students' focus on task interpretation (23 segments) outstripped their mentioning planning (18 segments), cognitive (16 segments), or monitoring/fix-up-related issues (16 segments).

Conclusions and discussion

Conclusions

Our goals in conducting this exploratory study were to develop a methodological framework for evaluating students' SRL in an engineering design activity and to identify patterns of students' SRL while solving a design problem. From the findings, we can conclude that the grade 9-12 students in this study placed more attention on understanding of task requirements than developing proper plans, selecting strategic actions to implement the plans, and monitoring activity in order to solve the design task. Gaps between students' interpreting task demands and selecting strategies for task completion and monitoring/self-adjusting approaches were apparent for both higher- and lower-achieving students at this level. The relatively high scores on students' understandings of tasks were also paralleled in their high scores on performance criteria.

Even for this high-performing sample of students, important differences in self-regulation were observed between relatively higher- and lower-achieving students. When looking across the two design phases studied (problem definition; conceptual design), overall mean comparisons on the EDQ revealed no statistically reliable group differences. However, some important differences were observed at the sub-phase level. For example, lower-performing students scored significantly higher on planning their design metrics refinement than did their high-performing peers. In contrast, higher performing students scored significantly higher than did lower-performing peers on selecting strategies to establish design means and monitoring and fix-up strategies to generate design alternatives. These findings combined to suggest that, even when lower-performing students may have been more active in planning, they were less likely than were high-achieving peers to translate those plans into action. Further, striking group differences across all SRL-features were revealed in notebook writings. Students who received the highest grades in their Engineering design courses also provided greater depth and specificity in their descriptions of task requirements and strategies used to achieve them.

Discussion

The first general principle for K-12 engineering education set by the Committee on K-12 Engineering Education is to emphasise engineering design in K-12 engineering education (Katehi et al, 2009). Despite a strong push to emphasise design in K-12 engineering education, research has found students, particularly in grades 9-12, to be less skillful in deploying good metacognitive skills in learning (Joseph, 2010; Lawanto, 2011, 2012; Mateos et al, 2008). Gaps between understanding task requirements and developing proper plans, selecting strategic actions to implement the plans, and monitoring design activity may hinder students in solving design problems more systematically. Thus, our findings here suggest that teachers should devote increased time to in-depth discussion of the design process and SRL strategies that may be critical to solving tasks in each phase throughout that design process. For example, teachers may allocate more time to support the students in transforming their understanding of the tasks into proper planning strategies. Also, encouraging students to discuss with their teammates about their understanding of what they are being asked to do in the design project may help them refine their interpretation of the tasks being asked of them. Teachers may offer their help in this process by encouraging the students to review their understanding of the task and to continually ask for help and clarification.

Differences between higher- and lower-performing students in their task interpretation and strategy use might be triggered by other issues such as emotions, task value, and creativity. Students with positive emotions while engaged in design task can persistently execute their strategies to achieve their goals (Pekrun et al, 2011). Similarly, students who express positive task value may perform better than those who see the activity as an unimportant, irrelevant, or uninteresting (Bong, 2001). Furthermore, creativity, which is considered as an essential factor for generating ideas (Barak, 2007), may also be able to explain why higher-performing students are less likely to report their planning strategies, but often execute relevant cognitive strategies well. Since creative students may dynamically change their design strategies, they may feel that is not too essential to report their planning strategies. In essence, some planning strategies become tacit knowledge (Polanyi, 1962). In contrast, students who are less creative may exhibit the ability to explicitly report their plans required to achieve their goals.

Since many of our findings were suggestive and this study was exploratory in nature, interpretation of the data should be done with caution and future work in this area is highly recommended. Three directions are proposed for the improvement of future work. First, studies with larger sample sizes are essential so that the generalisability of the findings can be determined. A larger sample size would add statistical power in evaluating differences between SRL features and across groups of students. Sampling from multiple schools, with learners at a larger range of achievement levels, may also assist in understanding individual differences in SRL as they unfold within a diversity of contexts. Second, future research should investigate connections between how engineering design activities are introduced and supported at Grade 9-12 levels and how students think about and engage in design processes. Having a better understanding of these connections may further help us in targeting how to shape classroom practices that enable self-regulation for secondary school students. Third, the second and third SRL features of Butler and Cartier's model (i.e., what individuals bring into context and mediating variables) should be included in our future works. Although the data analysis may become more complex, creativity, emotions, and task value may open doors to a better understanding of why students tend to have lower planning strategies when measured against their understanding of the design task and how higher- and lower-preforming students differ.

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