Student’s Self-Regulation in Managing Their Capstone Senior Design Projects

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Abstract

The objective of the present paper is to describe students’ self-regulation while working on their senior capstone design projects. The specific focus of this study was to understand how students manage their projects with their teammates on three major issues: Team Management, Resources Management and Time Management. Quantitative data associated with student Self-Regulated Learning (SRL) on project management were collected using our Engineering Design Metacognitive Questionnaire (EDMQ) survey instrument. Three hundred and fourteen students participated in the study. Data collected were evaluated quantitatively by comparing the mean value of each item from the same project-management-related issues (i.e., teamwork, time, and resources) across SRL episodes (i.e., task interpretation, planning strategies, cognitive strategies, and monitoring and fix-up strategies). The findings suggest Team strategies require a high level of student involvement and effort, while time strategies and resource management strategies are employed to a lesser degree, on average. Small differences were seen between male and female students in average strategy expression. Students may be benefitted by interventions designed to improve self-regulation for specific team management strategies employed by engineering students in relation to project management activities. Needed improvements touching on various strategic actions, as well as monitoring and fix-up strategies, are described in this paper.

Keywords: self-regulation, engineering design, project management

Introduction

Although teamwork has been recognized as one of the major skills practiced in the workplace, in educational settings it is often perceived by students as challenging and adding complexity to their design tasks. In engineering programs, students are expected to be able to work in teams and this expectation is even prescribed in one of the student outcomes endorsed by the Accreditation Board for Engineering and Technology (ABET) - Criterion 3. Student Outcomes (d).¹ Working on a design project in a team requires effective self-regulations. Students’ deficiencies in learning, including learning to work together in a team, are caused by a lack of self-regulation.² This article focuses only on students’ self-regulation, which is defined as a complex repository of knowledge and skills for planning, implementing, monitoring, evaluating, and continually improving the learning process, in the context of managing a design project. The educational implication of this project will be derived from the results to promote students’ self-regulation, particularly in managing their team efforts to complete engineering design challenges.

Self-Regulated Learning

Scholars define self-regulated learning (SRL), often shortened to self-regulation, in many different ways. However, they all have a common theme that suggests that self-regulation is a self-directed process each of us employ when engaged in any school- or non-school-related tasks. Zimmerman³ describes self-regulation as “self-generated thoughts, feelings, and behaviors that are oriented to attaining goals. Self-regulated individuals are skilled in goal-setting, self-monitoring, self-instruction, and self-reinforcement⁴ and “habits of mind” and commitment to the
ideals of reflective thinking, assessment, and learning as an ongoing, lifelong process. Therefore, it naturally follows, that students with good self-regulation are more likely to perform better in their academic work.  

In this study, a SRL model showing the dynamic and iterative interplay between metacognitive and cognitive activity described in Butler and Cartier’s model was used. In this model, SRL is characterized as a complex, dynamic, and situated learning process that comprises six central SRL features that interact with each other: (1) layers of context; (2) what individuals bring; (3) mediating variables; (4) task interpretation and personal objectives; (5) self-regulating strategies; and (6) cognitive strategies. The focus of our study presented in this article was student’s task interpretation, self-regulating (i.e., planning and monitoring/fix-up) and cognitive strategies, which we term strategic actions.

Task interpretation is the heart of the SRL model insofar as it shapes key dynamic and recursive self-regulating processes. When confronted with academic work, such as managing a team-based project, students draw upon information available in the environment, and knowledge, concepts, and perceptions derived from prior project management experiences to interpret the demands of a task. Students manage their engagement in academic work by using a variety of self-regulating strategies: 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.

Managing the time and resources students have to complete their project, as well as building and managing a supporting attitude toward their teammates, requires continuous adjustment and effort from each team member. Each member of the team needs to continuously assess their own understanding of those three critical issues and make necessary adjustments throughout the project duration. First, students need to be aware of available time and resources, and the scope of the project they each need to handle. Then, proper planning, action, monitoring and strategic directive and corrective actions need to be taken by each team member.

Project Management in Engineering Design Project

Many authors address the prevalent nature of hands-on design projects for engineering students in their senior year, particularly during senior capstone design courses. In completing their design projects, these engineering students typically work in a team with their fellow students. Working in a team isn’t always easy and often brings more complexity to the design project they are working on.

Working in a team is not just about working together with peers sharing the same space and tasks to work on, but also balancing power and responsibility as they seek to control the path their team takes to meet its mission. Numerous studies have suggested that group learning offers a basis for social comparison and social learning, and that teamwork quality and team diversity impact the effectiveness and quality of task completion.

In the context of engineering senior design projects, the project mission is accomplished as students manage the demands of tasks and assignments from clients (someone who inspires or supports the design project), the instructor and each other. In academic environments, there may
be a leader assigned to a particular team, yet members of the team are generally peers and the assignment of leadership may be arbitrary and quickly shift to a more loosely distributed form representative of social contexts students may be more familiar with. Thus, the distribution of power and responsibility is subject to the unique dynamics of each team. Thus student-led, team-based projects tend to reflect a form of project leadership workable and agreeable among project members. Kerzner\textsuperscript{16} defines project management as an approach for finding internal solutions to resource control issues and requires, “methods of restructuring management and adapting special management techniques, with the purpose of obtaining better control and use of existing resources” (p. 2). Project management in this work is comprised of three components: Team Management, Resources Management and Time Management. In Figure 1, we present a breakdown of the various components of project management used in this study.

![Table](image)

\*In context of capstone senior design courses

Figure 1. Division of components of Project Management as subdivided across the various aspects of a capstone senior design course. Divisions of Team, Time and Resources embody three strategy types that students employ during design project activities. The activities outlined above were part of the comprehensive EDMQ survey instrument specifically designed to characterize project management activities and self-regulation.

The separate components of project management each involve dynamic decision making and require a high level of self-regulation as students work to overcome the various challenges associated with each aspect of project management. Team management involves dynamic coordination of from 3-10 persons, their personalities and various agendas. Resource management is seen as the team allocation, tracking and use of facilities, tools and funding. Challenges range from undersized budgets to competing for crowded lab space and tools. In this study, time management is considered on an individual basis, as students prioritize work on their particular project tasks and coordinate with teammates to meet their pre-determined deadlines for delivering portions of the project. Time management is a unique component of project
management because it may represent one of the most “ill-defined” parameters within a capstone project. There may be due dates for course required milestones, but students are allowed to set a pace based on their own level of commitment to their team and their project.

The Study

The objective of this study was to describe students’ self-regulation while managing their capstone senior design project. The specific focus of this study was to understand how students manage their projects with their teammates on three major issues: Team Management, Resources Management and Time Management.

1. Research Questions

Two research questions were constructed to guide the study:

1. In what ways do students actively employ self-regulated learning during design activities of a capstone senior design course?
2. How do SRL activities differ between male and female students within these courses?

2. Participants

Three hundred and fourteen students from three institutions participated in this study. They were each working on senior design projects with teams having an average of 5 students each. Ten percent of those students (i.e., 31 students) were female and 50% of all students had a GPA between 3.00 and 4.00 on a 4-point scale.

The institutions involved in this study were all public, state universities from within the United States. One institution is located in the Mid-West, one in the Inter-Mountain West and one is located on the West Coast. Student design teams included electrical, mechanical, aerospace and biological engineering.

3. Data Collections/Analysis

Quantitative data were collected through a SRL survey instrument called Engineering Design Metacognitive Questionnaire (EDMQ). The instrument development is grounded in Butler and Cartier’s self-regulated learning (SRL) model which describes the interplay between motivation, cognition, and metacognition within academic activities such as design. The questionnaire is adapted from their work, including the Inquiry Learning Questionnaire and the Learning through Reading Questionnaire. A rubric matrix combined Butler and Cartier’s SRL features (i.e., Task Interpretation, Planning Strategies, Cognitive Actions, Monitoring and Fix-Up strategies) and the three project management components described (i.e., Team Management, Resources Management and Time Management), to construct each portion of the instrument. We use the term Strategic Actions rather than Cognitive Actions in the EDMQ and this study to avoid confusion with cognitive processes. There were 7, 11, and 12 items respectively, which assess student’s self-regulation of time, resources, and teamwork strategies, distributed across SRL features. Measurement scales of items for both instruments ranged from 1 to 4 (i.e., 1 = almost never, 2 = sometimes, 3 = often, 4 = almost always). The EDMQ was validated through iterative face and content validity processes. The Cronbach’s alpha for each
of the four SRL constructs, across EDMQ sub-tests, range between 0.85 and 0.92. The EDMQ was administered in phases corresponding to segments of Dym and Little’s design process throughout the duration of the capstone course, with a project management segment completed after the completion of the students’ projects. This final portion of the instrument assessed student use of project management strategies for the entire project.

Quantitative data from questionnaires were analyzed to create self-regulation profiles for the complete sample, and to evaluate self-regulation differences that might exist between females and males. As depicted in Figure 2, data collected from the EDMQ were evaluated as follows: First, all questionnaire items for each of the three project management components were averaged, giving a cursory comparison of usage. Second, mean values were calculated for the narrower set of questionnaire items associated with each SRL construct approach – task interpretation (TI), planning strategies (PS), strategic actions (SA), and monitoring/fix-up (M&F) – for each of the three strategy types averaged in step 1. Third, the initial strategy type average found in step one was subtracted from the mean values calculated for each SRL construct in step two. These were cataloged in Table 1. Fourth, a scale defining level of difference from the observed strategy mean was created that allows those SRL activities that differ in frequency of use within strategy types to stand out. The minimum difference for the purpose of this study was set at ±0.10, or approximately 3% of the strategy type average. The maximum difference observed was 0.23, or about 7% different than the mean for that strategy type. This level of granularity allows us to consider roughly half of the activities in some detail. Fifth, these targeted intersections of self-regulation and project management strategy type were analyzed in an effort to answer Research Question #1, and to provide implications for improved capstone design instruction. Sixth, differences between means for male and female students were compared and statistical tests were conducted to find any significant differences to answer Research Question #2.

![Figure 2. EDMQ data analysis flow diagram.](image)
Rankings of the strategy types used by students are also included within our findings so that aspects of project management that play a large, or lesser role, might be better understood. The priority associated with each strategy type may vary across institutions and individual persons, yet we anticipate that general patterns and conclusions can be extended to each unique institution and design project. These results also give an indication of what students generally perceive they are doing in regard to their own project and team involvement. Self-regulated activity higher than average for a strategy type will generally be considered positive, while lower than average values are anticipated to show areas lacking in development that could benefit from additional emphasis or instruction.

4. Findings

Addressing Research Question #1: In what ways do students actively employ self-regulated learning during design activities of a capstone senior design course?

In this study, 314 student responses showed dissimilar employment of the three types of design strategies found under the project management portion of the EDMQ (see Table 1). Teamwork strategies were employed most, having an average response of 3.30, followed by time (3.25) and then resource strategies (3.13). Areas of self-regulation above and below strategy means were marked in a table according to the degree of difference from the mean, or average value for all items of that strategy type. No particular designation was applied where the difference from the mean was less than 0.10. Several patterns in utilization of learning strategies are apparent, which are described later on. Positive values, corresponding to a specific aspect of SRL being implemented more frequently than average, stand in contrast to negative values, that correspond to less than average use. Simple divisions of delta values are denoted with one or more asterisk.

Table 1: Ranking of strategies used during Capstone Senior-Design courses (N= 314). Mean values in comparison to a 1-4 scale (i.e., 1 = almost never, 2 = sometimes, 3 = often, 4 = almost always). Column headers are TI – task interpretation, PS – planning strategies, SA – strategic actions, and M&F – monitoring and fix-up.

<table>
<thead>
<tr>
<th>Management Strategies Used</th>
<th>Mean Values</th>
<th>SRL Construct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TI</td>
</tr>
<tr>
<td>Teamwork Strategy Type</td>
<td>3.30</td>
<td>0.23 **</td>
</tr>
<tr>
<td>Time Strategy Type</td>
<td>3.25</td>
<td>0.20 **</td>
</tr>
<tr>
<td>Resources Strategy Type</td>
<td>3.13</td>
<td>0.20 **</td>
</tr>
</tbody>
</table>

* denotes $0.10 < \Delta < 0.19$   ** denotes $0.20 < \Delta < 0.29$

Team management added a level of complexity to design projects such that students devoted significant efforts to strategic activities concerning other team members. Students indicated that they were often engaged in teamwork strategies, but interactive strategies such as role negotiations, asking for help, or receiving help on difficult portions of design tasks, were not as frequently engaged in. Responses to EDMQ items regarding teamwork strategies indicate that much of what students think about revolves around doing their fair share in an overall effort to complete the project. Students showed they were intent on interpreting and defining what they should do to be a good team member.
On the other hand, they did not employ monitoring and fix-up strategies to evaluate whether they had actively participated in group activities, asked themselves whether their negotiations of roles were fair or adjusted adequately or asked for help to deal with difficult parts of their tasks. Despite this, items from the planning strategies and strategic actions constructs of SRL kept the team strategy average high with activities such as planning and attending group meetings, brainstorming, working to identify, deal with and clarify the critical parts of their individual tasks. The structure and apparent function of teams was there, as demonstrated by their planning of meetings and brainstorming together, but individual achievements and personal issues may have been more of a priority (see Table 2).

Table 2. Comparisons of SRL construct activity means across team management strategy type \((N=314)\). Team management had generally high responses indicating that it accounts for much of the activity students engage in during design projects.

<table>
<thead>
<tr>
<th>Task Interpretation</th>
<th>Planning Strategies</th>
<th>Strategic Actions</th>
<th>Monitoring and Fix-up</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>When I am working with my team, I need to...</td>
<td>As I start working with my team, I...</td>
<td>When I am working with my team, I am...</td>
<td>While I work with my team, I am...</td>
<td></td>
</tr>
<tr>
<td>do my fair share in an overall team’s effort to complete the project</td>
<td>identify and clarify my part in the team’s effort to arrive at a solution</td>
<td>planning and attending group meetings</td>
<td>evaluating whether I have completed my part in the project</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>brainstorming with my teammates to clarify and generate ideas as well as to develop solutions</td>
<td></td>
<td>asking myself if I have actively participated in the group’s activity (e.g., meeting, discussion, or brainstorming)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>working intensively to deal with the critical part (i.e., hard to finish) of my task</td>
<td></td>
<td>asking myself whether the negotiation I made to determine my role in my team is fair and making necessary adjustment if needed</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>further helping my teammates completing the project</td>
<td></td>
<td>asking for help to deal with the difficult part of my task, if needed</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>negotiating the role that I have to play and tasks that I have to do with my teammates</td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Time management strategies were mostly characterized by a focus on ensuring that their contribution would deliver their design tasks in a timely manner and in considering how much time was left and what they still needed to do. Despite this, students report that they did not often have, or follow, a working schedule, over the course of the project (see Table 3). This shows that students were attempting to regulate their activities over time, but did not utilize basic tools for
doing so. A failure to plan and commit things to a schedule could indicate an area of weakness leaving design teams vulnerable to setbacks and unforeseen delays.

Table 3. Comparisons of SRL construct item means across time management strategy types (N= 314). Students engaged in these activities less than team management activities, suggesting less attention to time than to interpersonal demands.

<table>
<thead>
<tr>
<th>Task Interpretation</th>
<th>Planning Strategies</th>
<th>Strategic Actions</th>
<th>Monitoring and Fix-up</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>When I am working with my team, I need to...</td>
<td>As I start working with my team, I...</td>
<td>When I am working with my team, I am...</td>
<td>While I work with my team, I am...</td>
<td></td>
</tr>
<tr>
<td>3.45 ensure that my contribution to the team will deliver the design tasks in a timely manner</td>
<td>3.09 ensure that I have a working schedule to follow throughout the design process</td>
<td>3.20 considering how I will be able to work through each required step in the time allotted</td>
<td>3.39 thinking about how much time is left, what I still have to do</td>
<td>1</td>
</tr>
<tr>
<td>3.16 When I am working with my team, I am... a) estimating the time needed to accomplish each part of the design tasks</td>
<td>3.19 helping my team to adjust our time schedule accordingly</td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4. Comparisons of SRL construct item means across resource management strategy types (N= 314). Means for resource management were lower than the other two strategies, possibly due to less perceived or actual control. Team leadership may have been more likely to engage in resource management activities than the average student.

<table>
<thead>
<tr>
<th>Task Interpretation</th>
<th>Planning Strategies</th>
<th>Strategic Actions</th>
<th>Monitoring and Fix-up</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>When I am working with my team, I need to...</td>
<td>As I start working with my team, I...</td>
<td>When I am working with my team, I am...</td>
<td>While I work with my team, I am...</td>
<td></td>
</tr>
<tr>
<td>3.33 seek relevant resources (e.g., materials/tools, information, skills, funding) needed</td>
<td>3.29 identify potential resources (e.g., materials/tools, information, skills, funding) to complete the design project</td>
<td>3.29 enhancing my skills or knowledge of procedure I need to have to solve our design tasks</td>
<td>3.23 refining the skills or knowledge of procedure to improve design outcome</td>
<td>1</td>
</tr>
<tr>
<td>3.18 searching for, selecting, and using working materials/tools, information, and funding sources we need</td>
<td>3.13 asking myself if I have found and selected appropriate resources</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>3.08 executing the budget as planned</td>
<td>3.12 further searching for better fit materials/tools or information whenever needed</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2.87 judging to see if we have used our project funding effectively</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2.76 checking if we need to adjust the budget</td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>
Resource management strategies followed both teamwork and time strategies and may be subject to a number of contextual differences. The average value for resource management strategies being lower than team and time management, indicates that there was likely not as much regulative loading for students in this area (see Table 4). This may be due to a number of factors such as financial constraints, limited hardware, software, lab space, advising or equipment choices determined by department characteristics and culture. Also, due to the nature of team leadership assignment and distribution of tasks, the degree of control had over resources may have been greater for some students than others. How much all these factors affect project outcomes is unclear, yet it was indicated in this study that resource management occurs differently than team and time management.

In analyzing the interaction of SRL constructs over these three strategy types reveals that task interpretation is employed more frequently and consistently than any other form of self-regulation. This “go-to” type of expression is contrasted by significantly lower monitoring strategies and variability in planning for design task demands. We cannot overstate the importance of proactive, self-regulated activity during senior design projects. Better monitoring of critical project needs, self-regulated actions to bring about greater performance and giving greater attention to schedule will likely have a deep impact on project outcomes. With such improvements in self-regulation, we might, with confidence, anticipate more successful outcomes for capstone design teams and better engineers, over-all.

Addressing Research Question #2: How do SRL activities differ between male and female students within these courses?

Female participants comprised 10% of self-identifying individuals in this sample, with 31 identifying as such. SRL activities differed between male and female participants in this study. Average values across strategies for team, time and resource management were greater for female participants than males (Team 3.37/3.30, Time 3.33/3.25, Resource 3.22/3.12), but there was not statistical difference found for those strategies ($p > .05$). Female employment of teamwork strategy was 2.3% higher over team management strategies than males, 1.9% higher over time management strategies and 3.2% higher over resource management strategies.

At a more specific level, female averages were higher than males for 16 items, while male averages surpass females for 12 items and 2 items with no inter-gender difference. Observable differences were more pronounced for higher female averages, but significance from a 2-tailed t-test for independent samples ($p < .05$) was only obtained for one item, but indicated that females tended to evaluate the fairness of negotiations of role and make adjustments where needed, more than their male classmates. Other items for which higher averages were obtained, but for which statistical significance was not obtained ($p > .05$) include:

- Considering how to work through each required step in the allotted time (3.44/3.17)
- Refining skills or knowledge of procedure to improve design outcome (3.44/3.17)
- Further searching for better fit materials, tools or information whenever needed (3.30/3.08)
- Helping the team adjust their schedule (3.41/3.20)
- Executing the budget as planned (3.30/3.07)
Based on these findings, we may conclude that for certain project management strategies expressed during design projects, female students outperform their male classmates by a small margin. Reasons for these subtle differences may be a valuable subject for additional study.

Conclusions and Discussion

Students approach project management of capstone design courses from a task interpretation standpoint of self-regulated learning. This is seen through significant attention devoted to understanding task demands, doing a fair share, completing on time and using proper resources. Strategic actions and monitoring of personal, team and project status were employed to a lesser degree. An area of significant concern lies in students’ infrequent efforts to define, update and adhere to a project schedule. Project teams may be more successful if scheduling and time management practices were practiced to a greater degree.

Students’ efforts tend to focus on their own assignments, skill development and role definition, with less effort aimed at utilizing the capacities of other team members. Teamwork was shown to take the most significant portion of student project management effort, confirming that teams add complexity to design situations. However, this may benefit students because the experience of being part of a team may play a significant developmental role for engineers. An area for further study could be to evaluate the effect on students’ ability to function as part of a team through earlier and more frequent project-based learning experiences.

Male and female students showed some difference in averages across project management strategies, with females employing slightly higher average self-regulation than their male classmates, but most differences were not statistically significant. This might be due to the sample size identified as female (i.e., 10% identified overall), which was relatively small, yet not uncommon among engineering disciplines. However, significance was found between the way male and female students monitored role negotiations within teams. Other minor differences existed, but may require further investigation. Both male and female students may benefit from additional emphasis in a number of focused areas.

Improvement of strategic actions and monitoring activities can serve to balance students’ self-regulations and enhance their learning experience in design. Specifically, students can improve their use of teamwork strategies by more consciously negotiating roles, helping each other finish difficult tasks, and more closely monitoring their participation and workload. Students can improve their use of time management strategies by implementing methods for estimating time to complete tasks, employing an effective project schedule and helping their team to adjust their schedule and expectations according to performance. Students also can improve their use of resource management strategies by searching for resources, executing budgets as planned and by monitoring their budgets, and assessing the effectiveness of resources already acquired.

Educators support students to improve self-regulation of project management by explicitly addressing how to track and estimate task duration. They can help students properly scope and frame functions and outcomes so that depth of design is achieved, while considering limitations of budgets, time and available human capitol. Providing suggestions and instruction regarding reflective thinking and monitoring of personal and team efforts throughout the design process may be beneficial, as will be timely feedback regarding missing aspects of self-
regulation, especially regarding schedule creation and adherence. Instructors can also address how power and responsibility are distributed among teammates by re-thinking group leadership strategies for the classroom and design group. They might also seek to address other aspects of team management, such as the ability to ask for help from, or support, a teammate in a difficult spot. Such coaching might need to occur on a very individual scale. Lastly, fostering self-regulation of engineering students requires a deliberate, metacognitive attempt to develop and recognize one’s own self-regulation in learning and teaching.

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