Students' Self-Regulation in Senior Capstone Design Projects

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Abstract

Self-regulation is defined broadly as a complex repository of knowledge and skills for planning, implementing, monitoring, evaluating, and continually improving the learning process. Studies have found that consistent use of self-regulation in an academic setting is highly correlated with student achievement. Self-regulation plays a critical role in problem-solving, particularly when unraveling ill-structured problems such as engineering design. The major aim of this five-year research project is to study the self-regulated learning (SRL) activities of college seniors engaged in a capstone engineering design project. This project is grounded in Butler and Cartier's SRL model, which describes the interplay between affect, motivation, cognition, and metacognition within academic engineering design activities. Dym & Little's design process model was also used as sensitizing theoretical framework. Specific objectives of the research activities in this project are to (1) Build research protocols and tools for studying student self-regulation; (2) Describe the self-regulation strategies in which students engage during engineering design processes and project management; (3) Strengthen educational practices through the development of activities to communicate the role of self-regulation in design to engineering educators and students. At present time, the project has successfully completed the first two objectives; however, the qualitative data analyses are not yet finished. Moreover, a teaching guide and workshop to strengthen engineering design practices by promoting the role of self-regulation to engineering educators and students are currently developed.

1) What is Self-Regulation?

This five-year project studies the self-regulated learning (SRL) activities of college seniors engaged in a capstone engineering design project. The project is currently at its final year and it is not yet finished. Some qualitative data analysis and educational activities are not yet fully completed. Therefore, the researcher will request an extension for the project for one more year.

Self-regulated learning (SRL), or self-regulation, is defined broadly as a complex repository of knowledge and skills for planning, implementing, monitoring, evaluating, and continually improving the learning process [1]. The effective use of self-regulation helps a student oversee his or her learning process by interpreting requirements, planning and monitoring ongoing cognitive activities, and comparing outcomes with internal and external standards [2].

The influence of SRL in learning and problem solving has been demonstrated extensively [3]–[5]. Zimmerman and Pons [6] found that consistency in employing self-regulated learning strategies is highly correlated with student achievement. Schoenfeld [7] argued that an unsuccessful problem-solving effort may result from the absence of assessments and strategic decisions. Thus, students with poor self-regulation may benefit from training to improve self-regulation and subsequent learning performance [8].

This 5-year National Science Foundation (NSF) funded project uses Butler and Cartier's SRL model [9]–[11] that involves six central 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.

2) Self-Regulation in Engineering Design Tasks

Because design tasks are typically complex, ill structured, and involve multiple phases, the SRL features depicted in the Butler and Cartier's model offer a powerful framework for studying how students engage in solving a design task. First, *layers of context* may include learning environments such as a country, state/province, school, a particular classroom, teachers, instructional approaches, curricula, and learning activities. In engineering education, contexts also include learning expectations in design courses, the nature of particular design tasks, and the expectations of the instructor. Recognizing the ways in which multiple interlocking contexts shape and constrain the quality of student engagement in learning is essential for understanding SRL. According to Butler and Cartier, students' engagement in SRL also depends on *what individuals bring to the context* (e.g., strengths, challenges, interests, and preferences). Over time, students accumulate a learning history that shapes their development of knowledge, skills, self-perceptions, attitudes toward school, and concepts about academic work [12]–[14]. Correspondingly, *mediating variables*, which influence the quality of students' engagement in self-regulation, include students' knowledge, perceptions about competence and control over learning, and perceptions about activities and tasks. *Mediating variables* also include emotions experienced before, during, and after completing a design task.

The fourth feature in the Butler and Cartier's model includes student *task interpretation and personal objectives*. When confronted with academic tasks, students draw upon information available in the environment, and knowledge, concepts, and perceptions derived from prior learning experiences to interpret the demands of a task [10], [15], [16]. Task interpretation in engineering design involves identifying tasks essential for every design phase (e.g., during problem definition, conceptual design, etc.). For example, during the problem definition phase of a design task, students ideally focus their efforts on clarifying design objectives and design constraints. Interpretation of task demands is a key determinant of the goals students set while learning, the strategies they select to achieve those goals, and the criteria they use to self-assess and evaluate outcomes [10], [15], [17]. Students also set personal objectives such as achieving task expectations to direct their engagement in designing. Based on their task interpretation, students ideally set personal goals to achieve task demands effectively.

Fifth, students manage their engagement in academic work by using a variety of self-regulating processes, including planning, monitoring, evaluating, adjusting approaches to learning, and managing motivation and emotions. In the best-case scenario, students draw on productive interpretations of task requirements to choose and enact these dynamic and recursive processes. Self-regulation processes are iterative and dynamic endeavors that shape how students engage with a design problem.

Finally, as part of their engagement in the "iterative cycles of strategic action", students select and enact relevant cognitive strategies (i.e., enacting strategies for accomplishing requirements of design tasks). Strategy use is ideally embedded thoughtfully and adaptively in cycles of strategic action, as learners identify goals, plan courses of action, self-monitor progress, and adjust goals, plans, or strategies based upon self-perceptions of progress or feedback and performance.

3) The Five-Year Project (2012-2017)

The long-term goal of this research effort is to improve the design skills of undergraduate engineering students through the practice of SRL. The practice of SRL develops students' awareness of their thinking through metacognition. This project connects research and educational activities with the dual aim of better understanding and improving engineering student design processes.

a) Research Activities

The central goal of this research is twofold: (1) to develop and validate a suite of methodological tools to study metacognition in engineering design activities; and (2) to describe the metacognition of students engaged in a design activity. This study is conducted in two phases. The main research components (Phases 1 and 2, described below) utilize a descriptive study to investigate student self-regulation and the types of self-regulating and cognitive strategies employed during engineering design activities, in order to identify potential challenges. The project utilizes rigorous research methodologies that involve complex data collection and analysis processes. An extension of research is integrated into the educational activities that are informed by the main research.

Senior capstone design projects were selected to be the context of this research activity because they represent ubiquitous, complex, and ill-structured problems that prepare students with industrially-based projects [18], [19]. The majority of engineering students reported that they were exposed to hands-on design projects in their senior year, particularly during senior capstone design courses [20]. As suggested by Black [8, p.28], "engineering schools need to have a clear mission focus that reflects the needs of their industrial customers and their place among all engineering schools." Having a better understanding of student SRL activities will help engineering educators to design and implement teaching interventions that promote student metacognitive awareness.

i) Phase 1: Quantitative Study – Breadth View (Completed)

The objectives of this phase were to: (1) validate the SRL survey instrument; and (2) study self-regulation in a large-scale administration. During Phase 1, the researcher gathered data from 307 seniors from several engineering colleges to validate an adapted SRL survey instrument called Engineering Design Metacognitive Questionnaire (EDMQ). The 127-item EDMQ, which assess student's self-regulation while engaged in an engineering design project, was developed, field-tested, and used. Web-based engineering design notebook (eJournal or eJ) was also designed, developed, and used by students to archive and organize their project tasks and design outcomes. This phase enabled the researcher to use the tool in subsequent research.

ii) Phase 2: Mixed-method Concurrent Triangulation Study – Depth View (in Progress)

The objectives of this phase are to: (1) do a small, focused study to hone in on patterns observed in Phase 1 and to enrich understanding about metacognition by investigating what students think about engineering design activities in relation to what they actually do; and (2) continue to build tools while also enriching understanding about metacognition.

During early Phase 2, the project focused on designing and building a suite of methodological tools (in addition to the EDMQ) for studying how 25 students engaged in the design process. Tools included the survey instrument (i.e., EDMQ), e-Journal (or eJ), and design artifacts. Interview sessions assessed students' experience and perception about design tasks and their engagement within the team. Throughout the design process, students reported planning, design strategies, and progress on design outcomes (photographs or electronic files of design artifacts) through eJ. A mixed method concurrent triangulation design [21] is being used in this phase to "confirm, cross-validate, or corroborate findings within a single study" [p. 215].

b) Educational Activities

A key aim of the educational activities is to strengthen practices by promoting the role of metacognition in design to engineering educators and students. To achieve that goal, three major activities are planned:

i) Develop a Teaching Guide and Monitor New Teaching Intervention

The principles for the intervention will come from the findings of the research activities at the secondary and post-secondary levels, focused on promoting SRL in engineering design. The aim is to build and field test particular interventions in an engineering context, to continue to advance understanding through putting theories into practice, and to evaluate and refine practices

The researcher will develop a teaching guide that provides principles, materials, and guidelines to help educators develop their own instructional material to promote self-regulated learning for engineering design courses. This guide is useful because teaching metacognitive strategies are not generic across subject matters. Any attempts to teach them as generic can lead to failure in transfer [22]. The goal is to train students to improve control over design engagement and performance.

ii) The Role of Cognition in Engineering Education Course (EED 7210)

The Doctorate of Philosophy in Engineering Education program at USU emphasizes the utilization of engineering skills and methods to conduct rigorous educational research to investigate educational problems affecting the engineering community. SRL is one of the topics discussed in this course; however, due to the limited material on this topic in the engineering context, students draw knowledge about metacognition from the sciences. The researcher will build upon the research experience and the findings of this project and offer EED 7210 students first-hand experiences in conducting research in SRL and participation in building a SRL knowledge base in engineering.

iii) Workshops

Based on the research findings, the researcher is currently developing a workshop on metacognition in engineering design education to introduce metacognitive awareness as a new teaching intervention for engineering design courses at USU and other institutional settings (e.g., the American Society of Engineering Education). The workshops will include presentations, discussions, and tutorials to deepen participants' understanding about what metacognition is, why it is essential for engineering education, and how it can be incorporated and assessed in engineering instruction. The EDMQ will be available online, and workshop participants will be invited to use it to see how they are making a difference in improving student design skills. The EDMQ may be used as a tool to evaluate where students are at different stages of a design activity. Collaborations among institutions will be built at this stage.

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