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Metacognitive Engagement During Problem Solving While in Naturalistic Homework Study Groups*

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Metacognitive regulation is a required activity when attempting to solve well-structured word problems. The purpose of this study was to understand the ways in which undergraduate engineering students engage in metacognitive regulation while working on homework in naturally formed study groups. Using ethnographically informed participant observations, three naturally formed groups were observed as they engaged in self-structured work around well-structured engineering homework problems. Using the Naturalistic Observations of Metacognition in Engineering (NOME) protocol, metacognitive regulation behaviors were identified throughout the observations. Behaviors like using a homework format (planning), checking an answer with a peer (monitoring), and discussing reasonableness of a solution (evaluation) are a few of the examples observed by participants. Descriptions of the regulatory behaviors as well as rankings of the rate of engagement are discussed. Metacognitive monitoring activities were observed most frequently while metacognitive evaluation activities were observed least frequently. Implications for research and practice are discussed.

Keywords: observations; metacognitive regulation; problem solving; ethnography

1. Introduction

A significant goal of educators is to prepare graduates to apply the knowledge gained in their studies to solve problems and make societal improvements. Educators focus on developing problem solving skills in almost every discipline because solving problems is universal to everyday life. The types of problems that practitioners encounter are different based on discipline and context. Due to this reality, educators engage their students in problem solving in very different ways based on their disciplinary perspective [1]. For example, students in the medical profession engage in problem solving through the practice of diagnosing illness and ailments. Business students read case studies that represent different examples of real life scenarios and generate action plans based on the information available. Law students construct arguments to cases proposed by their professors to practice rule-solving problems. Engineering students engage in design projects and develop solutions to problems posed in stories that provide contextual information about real world problems. Though disciplinary educators use different methods to teach problem solving skills, they all have the end goal of teaching future generations about skills necessary for disciplinary thinking to solve societal problems. One such skill necessary for successful problem solving is metacognition.

Significant research describes the benefits of engagement in metacognitive behaviors for learning and problem solving. For example, Chi, Bassok, Lewis, Reinmann, and Glaser [2] found that students who engaged in self-explanations, and thus engaged in more self-monitoring activities, tended to be better problem solvers. However, little is known about how students actually engage in metacognition in naturalistic settings [3]. Moreover, there is minimal research that examines if students actually engage in metacognitive behaviors during self-directed learning activities, such as studying problem solving material. This research study focuses on how students engage in metacognitive behaviors in engineering and what contextual factors support engagement in metacognition. The purpose of this study was to explore and describe the ways in which engineering students engage in metacognition to support problem solving activities under their own volition, without the intervention of a research agenda. In addressing this purpose, we provide a rich description of what metacognitive engagement looks like for engineering students in a naturalistic setting, specifically in a study group environment focused on problem solving activities.

2. Literature Review

2.1 Defining Problem Solving Activities

Problem solving is defined as "goal-oriented activity where the path or means to the goal is at least somewhat uncertain" [4]. Problem solving requires

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the student to think in a way that is directed towards achieving the goal of solving a problem. Metacognition, and specifically awareness and the management of mental processes, is necessary to guide the goal directed thinking in problem solving. Davidson and Sternberg [5] believe that it is one's ability to think about their problem solving activities that defines him or her as a good problem solver. In their chapter on problem solving, Davidson and Sternberg [5] use theoretical and empirical evidence from multiple perspectives including cognitive science, mathematics, reading comprehension, and the physical sciences to discuss how metacognition plays a key role in the three major areas of problem solving: the givens, the goals and the obstacles.

2.1.1 Givens

The 'givens' are identified as "the elements, their relations, and the conditions that compose the initial form of a problem," [5]. When identifying the 'givens', or given information, in a problem, the solver encodes the information from the problem and develops a mental representation of the problem. This mental representation is a map or picture, developed in the mind that represents the current state of the problem. Metacognition is used to determine what is known about the problem and what is unknown. The known information as well as the information to be found is identified as the 'givens' of the problem. Once this mental representation is developed, metacognition (specifically monitoring and evaluation) is used to change the mental representation from the original state to the goal state.

2.1.2 Goals

The 'goal' is defined as "the desired outcome or solution," [5]. When working towards the goal of a solved problem, the metacognitive strategy of planning is used to develop the plan that is to be followed. Some research has shown that a person's level of domain-specific knowledge can affect planning, as experts have been shown to spend more time planning while novices tend to spend less time planning (e.g., [6]). Also, it has been found that planning substeps to reach the final goal is actually easier than making a singular plan to reach the final goal [7].

2.1.3 Obstacles

As students work towards achieving goals, they may encounter a series of obstacles. 'Obstacles' are defined as "the characteristics of both the problem and the student that make it difficult for the student to change the given state of the problem into the desired one or to recognize when the correct transformation has occurred" [5]. The metacognitive strategies of monitoring and evaluation have been identified as critical steps used in addressing obstacles during problem solving. Without monitoring and evaluation, obstacles can become stopping points for students during problem solving. When students reach obstacles that are difficult to pass, teacher interventions that offer new problem solving strategies and encourage students to reflect on their progress have been shown to be useful in helping students move past obstacles [5].

2.2 Variations of Problems

The problems present in everyday life differ along three dimensions: problem type, problem representation, and individual differences of the problem solver [1, 8, 9].

2.2.1 Problem Types

The types of problems presented to students in learning environments vary by their structuredness, complexity, and abstractness. Structuredness refers to the level of structure provided in the problem prompt. Structuredness lies on a continuum of ill-structured, where some of the problem elements are unknown, multiple solutions may exist to the problem, there are multiple criteria that can be used to assess the problem and judgements or personal beliefs may need to be used to develop a solution, and well-structured problems, where most of the problem elements are known, there are a limited number of actions required to get to a solution, and a limited number of knowable solutions exist. The complexity of the solution relates to "the number of issues, functions, or variables involved in the problem; the degree of connectivity among those properties; the type of functional relationship among those properties; and the stability among the properties of the problem over time" [1]. The abstractness relates to how the problem is situated in the domain and thus is dependent on the context of the problem prompt.

2.2.2 Problem Representation

A problem presented to a learner also varies by the context and modality of the problem presented [1]. Problems are situated in the context or domain of the problem prompt. The context requires the solver to organize information in terms of relevancy and construct a representation of the problem space that is relevant to the problem being solved. The modality of the problem is represented by the real-life nature of the problem presented to the learner, or whether they include real-life concerns like budget constraints and time constraints as considerations in the problem context.

2.2.3 Individual Differences

Problems also differ based on individual differences of each learner that will approach the problem prompt [1]. Individual differences that impact problem solving include familiarity with the type of problem being presented, depth of domain knowledge where the problem is situated, cognitive control, metacognitive skill, epistemological beliefs, affective and conative components, and general problem solving skills.

2.3 Problem-Solving in Engineering Education

One important facet of the engineering profession is the ability to define and resolve problems [10]. Within engineering education, metacognition has been shown to be a critical thinking process in problem solving. For example, Litzinger et al. [11] conducted a study to look at the critical cognitive and metacognitive strategies that students engaged in while problem solving in statics. To achieve this aim, the researchers asked students to participate in think-alouds with different statics problems. Participants were first clustered into two groups (strong and weak problem solvers) by looking at a combination of their scores on a statics concept inventory, two spatial reasoning tests, and their SAT scores. Participants were then asked to complete two statics problems while thinking aloud. Utterances of metacognitive monitoring and evaluating were counted for each problem completed by participants. Litzinger et al. [11] found that stronger problem solvers used a higher rate of metacognitive monitoring than did weaker problem solvers. The research team also found that all participants used a higher rate of metacognitive monitoring when compared to metacognitive evaluation in order to solve the statics problems presented.

While not focused specifically in the area of problem solving, Lawanto [12] researched how engineering students' engagement in metacognition changed over the course of an ill-structured design project. Through a quantitative self-report study, Lawanto [12] found that a series of internal and external factors could be attributed to changes in metacognition over the course of a design project. Internal factors such as misjudging the complexity of the task, being fearful and failing, and misjudging one's own ability were cited as factors affecting metacognitive engagement. External factors such as lack of time, lack of support or resources, and receiving helps from others were also cited as factors impacting metacognitive engagement. Lawanto, Butler, Cartier, Santoso, and Goodridge [13] also found that higher performing learners engaged in more monitoring processes than lower performing students while working on engineering design problems.

2.4 Metacognition

Metacognition is defined as a learner's knowledge about and regulation of their own cognition [14, 15]. Metacognition is broken into two components: knowledge of cognition and regulation of cognition. Knowledge of cognition, or metacognitive knowledge, is described as the insight that the learner has about his own cognitive processes [14, 15]. Regulation of cognition refers to the activities that a learner uses to oversee his or her learning [15]. Within educational research, there is still significant debate as to what the theoretical model of metacognitive regulation should encompass. Consequently, there is no clear agreement, to date, on which metacognitive strategies should be included in the theoretical model of metacognitive regulation [16]. The strategies that have been included in this review are the most highly discussed strategies by experts in the field at this time (e.g., [15, 17–19]) and include planning, monitoring, evaluating, and control [15, 17–19]. Table 1 includes definitions and examples relative to an engineering problem-solving context.

The order in which metacognitive regulatory

Table 1. Metacognitive Regulation: Definitions and Examples

Term	Definition	Examples
Planning	Activities that involve the selection of procedures necessary for performing a task, predicting the outcomes of learning, and scheduling the strategies used to learn [15, 19].	At the beginning of a study group session, a student in a study group tells the rest of the group they are going to start with problem 1 and then proceed to problem 2 once the group finishes problem one.
Monitoring	Ongoing on-task assessment of task performance, observation of a person's level of knowledge as well as the act of testing and revising knowledge and strategies used for completing a task [15, 19].	After looking at the work on their paper, a student exclaims "I messed something up!" and proceeds to change their work.
Evaluation	The process of checking whether the way in which a task was accomplished was efficient and effective when compared to some criteria or standard [15].	After completing a problem, a student looks at their watch and states that they are ahead of their expected schedule for the evening.
Control	Activities that show evidence of a change in how a task is being approached due to engaging in some monitoring activity [18, 20].	After determining that a mistake was made on a calculation, a student erases the writing on their paper and proceeds to begin the calculation process again.

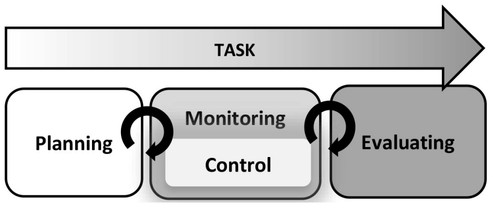


Fig. 1. Metacognitive Strategies over Lifecycle of a Task.

strategies are engaged in over the lifecycle of a task can be visualized in Fig. 1, which was developed by drawing on the work of Winne and Hadwin [21] and Nilson [22]. As the task begins, the learner would be expected to identify the goal of the task, identify strategies that could be used to complete the task, and then assign certain responsibilities to different study group members, if the work is done collaboratively (planning). Once the task has been started, the learner then actively assesses progress and performance throughout the task (monitoring). If a specific strategy is deemed ineffective while working on the task, the learner identifies a new strategy, switches to the new strategy (control), and then continues to assess progress and performance (monitoring). In order for a task to be completed, the learner must determine if the original goal has been met (evaluation). Once the task is complete, the learner reflects and determines if the strategies were efficient and effective at solving the task (evaluation). If the strategy is deemed effective and efficient, the learner can store that strategy in memory as the strategy to be used in the event that a similar task is encountered. While this order seems very linear in nature, it is important to note that actual progress on a task is not so linear in a natural setting. As the task at hand is defined and redefined, the learner moves back and forth between planning, monitoring/control, and evaluating. This back and forth movement is represented by the arrows in Fig. 1.

3. Purpose

The purpose of this study was to explore and describe the ways in which engineering students engage in metacognition under their own volition, without the intervention of a research agenda. Understanding how students engage in metacognition in self-directed learning environments provides a view of their level of metacognitive skill as well as their willingness to enact skills for use in learning and problem solving. This baseline information should help with the development of pedagogies focused on developing metacognitive skills in undergraduate engineering students. Herein, we focus specifically on engagement in metacognitive regulation though the larger study also considered metacognitive knowledge [23]. The aim is to provide a qualitative overview of the skills observed to provide a starting point for future research and educational development activities.

4. Methods

4.1 Research Design – Ethnographically Informed Qualitative Methods

To address our purpose, we designed an ethnographically informed qualitative study. Broadly, ethnography is the pursuit of understanding the human species and is typically used to understand human behavior [24]. Ethnographically informed means that we used inspiration from ethnographic methods such as participant observations and ethnographic interviews to design the methodology for this study without conducting all typical procedural elements of a true ethnographic study. Consistent with traditional ethnographic research [24, 25], we used participant observations as the primary method of data collection. Participant observation is the strategy of immersing oneself in the research field to experience and note events. Glesne [26] describes the main outcome of participant observation as the understanding of the participants, their behavior, and the setting. The data collection techniques used in this study follow a similar structure to ethnographic studies while the data analysis techniques diverge based on the outcomes pursued

For this study, the primary researcher acted as a passive participant observer who was partially known to the participants during observations. This means that participants knew that the researcher was observing their learning habits but did not know that they were specifically being observed for their engagement in metacognitive habits. Being a passive participant allowed the researcher to ask questions of the participants when necessary without significantly altering the context of the study group session.

4.2 Research Site and Participants

Participants in this study were students at a Small Teaching Focused College (STFC). This school has approximately 2,000 undergraduate students, most of which major in an engineering discipline, science, or math. Class sizes typically range from 20–25 students per class. STFC offers a range of extracurricular student programing, including athletics, fraternities and sororities, arts programming, technical clubs, and religious clubs. A majority of students at STFC participate in at least one extracurricular activity. Approximately 99% of students graduate from STFC with offers of employment. STFC has been noted for its excellence in teaching and is nationally recognized as a top undergraduate engineering institution in the United States. This research site was particularly beneficial for this study because the institution has a culture that promotes collaborative learning through class group projects, extracurricular group design projects, space allocations for group study and group work, and small class sizes that allow for more personal contact among the class population.

4.2.1 Course and Recruitment

The course selected for study at STFC was a sophomore engineering course that focused on teaching a problem solving heuristic (PSH) in the domain of conservation and accounting principles. The PSH course was taught in the mechanical engineering department but included mechanical and biomedical engineering students. Due to high enrollment (270 students total) and small class sizes, this course was taught over nine sections by six different instructors. The course met four times per week for 10 weeks. Each class session was 50 minutes in length. Classes were primarily lecture based, though some instructors did integrate active learning activities at different times throughout the academic term. The course had a common syllabus, common homework assignments, and common exams. Two homework assignments were due each week and typically consisted of solving four open-ended problems. While students were required to turn in individual homework assignments, students were allowed to work in groups to complete these assignments. Four examinations were conducted over the period of the academic term. Three exams were conducted during the term and were non-cumulative. One exam was conducted at the end of the academic term and was cumulative. Instructors had liberty to give quizzes and extra assignments to their specific course sections as they felt necessary. This course was selected because it offered access to a large population of students and was identified as one of the most difficult problem solving courses in the sophomore year at STFC.

The course focuses on teaching conservation and accounting phenomena (conservation of mass, conservation of linear momentum, conservation of angular momentum, conservation of energy, accounting of entropy), the approach taught in this PSH course focuses on teaching the students to situate the problems they encounter with the following questions, referred to as the four Q's in the textbook:

1. How is it calculated?
2. How is it stored?
3. How is it transported?
4. How is it created or destroyed?

Students are taught to solve all problems in the course using the Accounting Principle:

$$\underbrace{\begin{bmatrix}\text{Stuff}\\ \textit{accumulated}\\ \text{inside the}\\ \text{system}\\ \text{during a}\\ \text{time period}\end{bmatrix}}_{\text{Accumulation}} = \underbrace{\begin{bmatrix}\text{Stuff}\\ \textit{entering}\\ \text{the system}\\ \text{during a}\\ \text{time period}\end{bmatrix}}_{\text{Input}} - \underbrace{\begin{bmatrix}\text{Stuff}\\ \textit{leaving}\\ \text{the system}\\ \text{during a}\\ \text{time period}\end{bmatrix}}_{\text{Output}} + \underbrace{\begin{bmatrix}\text{Stuff}\\ \textit{produced}\\ \text{inside}\\ \text{the system}\\ \text{during a}\\ \text{time period}\end{bmatrix}}_{\text{Produced}} - \underbrace{\begin{bmatrix}\text{Stuff}\\ \textit{consumed}\\ \text{inside}\\ \text{the system}\\ \text{during a}\\ \text{time period}\end{bmatrix}}_{\text{Consumed}}$$

Recruitment occurred primarily through face to face contact. With permission from the instructors, six of the nine sections (approximately 180 students) were contacted. During the second and third class days, the primary researcher made an announcement at the beginning of the class in order to recruit naturally formed study groups to participate in the research study. After a short description of the study, interested students were asked to write down their names and email addresses on provided slips of paper so the primary researcher could contact them with further details. After 2 days of recruitment, 41 potential participants were identified. An email was sent to each potential participant further describing the study and asking one contact member from each study group to contact the primary researcher to set up an initial observation. Three study groups responded and initial observations were scheduled. Snacks for each study group session observed were provided as the incentive for participating in this study.

4.2.2 Researcher Participation

The primary researcher observed every study session of each study group that extended an invitation. The times and locations of each study session were dictated by the study group. Each observation was video and audio recorded. For each observation, a camera was positioned such that the faces of each participant as well as their work on the table where they were seated were visible. The researcher was positioned away from the table to create separation from the participants. Extensive field notes were taken during each study session and observation. While there was no protocol for the observations, attention was focused on listening for utterances of metacognitive engagement in order to record what events were occurring before, during, and after utterances. Interaction with the participants during these observations was minimal. At times, participants would talk to or ask questions of the primary researcher. All questions or comments were answered succinctly so as to minimize the impact of a researcher being in the room. On a few occasions, events of interest occurred that the primary researcher asked about at the end of the observation before the study group left.

4.2.3 Participants

Three study groups participated in this study, with a total of 14 students, though that number fluctuated from week to week because some participants only studied occasionally with their study groups. Each study group had a specific location (or set of locations) where they met to study. Study groups were identified as follows based on primary meeting location: Study Group 1, the off campus housing study group, or OFF; Study Group 2, the library study group, or LIB; and Study Group 3, the on-campus housing team, or ON. Table 2 provides information about each individual participant in this study.

Note on Sample Size

The purpose of this qualitative study is to give rich descriptions of metacognitive behaviors students engage in when controlling their own learning environment (e.g., homework study group). While some may be concerned about a small sample size of 14 participants for this study, it is important to note that the data collected from these participants encompasses over 40 hours of observation of homework study time among the three groups. The researcher for this study, through extensive time spent with study subjects, reached a point of data saturation in the last observations. Therefore, the sample size of 14 participants and 40 hours of observation data is sufficient for the purpose of this study. Moreover, methodologists and researchers have demonstrated the value of small sample sizes for informing engineering education [27–29].

4.2.4 Data Collection and Analysis

Over the academic term, 18 observations were conducted across all three study groups for a total time of 43 hours. Nine observations were selected for further analysis because they represented a range of scenarios and events of interest during the academic term, and also provided a variety of situations for a comparative analysis of metacognitive engagement.

Each observation was transcribed and qualitatively coded using the methodological procedure and coding strategy called the Naturalistic Observations of Metacognition in Engineering coding strategy [30]. Once coded, the data from each observation was quantitized in order to look for patterns among the data. Quantitization of qualitative data is a generally accepted practice in research when looking to identify patterns in the qualitative data that may not be seen by qualitative methods alone [31]. In order to look for patterns in the coded data, the metacognitive codes were quantitized and bar charts were developed for each observation. The method of quantitizing data is

Table 2. Participants for metacognition study

Group #	Location and Study Environment	Study Session Structure	Name	Course Section	Major	Sex	Race/ Ethnicity
OFF	Fraternity house dining room (common location for house).	Sessions started at 9pm the night before a homework assignment was due; schedule for sessions was random.	Adam	B	ME	Male	White
			David	B	ME	male	White
			Leonard	A	ME	male	White
			Terry	A	ME	male	White
			William	B	ME	male	White
			Daniel	Other	ME	male	White
LIB	Library study room with closed door.	Sessions typically started at 8pm two nights before a homework was due; team had a set meeting schedule each week.	Benjamin	B	ME	male	White
			Becca	B	BME	female	White
			Jenny	B	BME	female	White
			Michael	B	ME	male	White
			Gary	A	ME	male	White
			Cara	D	BME	female	White
ON	Common study area in dorm.	Sessions started at different times (start between 4:30pm and 12:30am) one night before a homework assignment was due; schedule for sessions was random.	Chris	D	ME	male	White
			Wilson	D	ME	male	Asian

not a method traditionally used with ethnographically informed work. However, quantitization does align well with the purpose of this research study.

To display information on the types of metacognitive behaviors in which students were engaging, a series of pareto charts was developed in order to display not only the behaviors observed but also a rate of engagement in each behavior. The rate of engagement (observed behaviors per minute) was a reporting value originally used by Whitebread et al. [19] for reporting the behaviors of the children in their study. In order to work toward developing a consistent language for which to compare results, we adopted a similar procedure for reporting numerical values associated with participant behaviors. Reporting as a rate of engagement is also helpful in that it eliminates length of the observation as a parameter for comparison. The study sessions were controlled by the participants of the study groups. Therefore, the length of the observations varied in length from 1 hour to 4 hours. In order to provide a way to compare metacognitive engagement among the different observations, engagement was reported as a rate in order to normalize the data among differing observation lengths.

Using turns as a method for counting, rates for metacognitive knowledge and metacognitive regulation were calculated using the following equation:

$$\textit{Rate of observed behavior} = \frac{\#\ \textit{of turns coded for metacognitive behavior}}{\textit{Duration of Observation in Minutes}} \tag{1}$$

The units associated with the rate of observed behavior are observed behaviors per minute. In their study of metacognitive regulation in collaborative learning among veterinary students, Volet, Vauras, Khosa, and Iiskala [32] defined a turn as a verbal comment or phrase from one individual until another student joined the conversation. Any discussion is made up of a series of turns, which represents participants going back and forth in a conversation. Turns are one way of quantitizing units in a conversation.

Metacognitive regulation behaviors were further broken down to show engagement in the primary categories from the coding strategy (planning, evaluation, etc.). For example, the metacognitive regulation bar is broken into segments representing the rate of observed behavior in planning, monitoring, evaluating, and control strategies. Those percentages were calculated using the following equations.

$$\textit{Planning Rate} = \frac{\#\ \textit{of turns coded as Planning}}{\textit{Duration of Observation in Minutes}} \tag{2}$$

$$\textit{Monitoring Rate} = \frac{\#\ \textit{of turns coded as Monitoring}}{\textit{Duration of Observation in Minutes}} \tag{3}$$

$$\textit{Evaluation Rate} = \frac{\#\ \textit{of turns coded as Evaluation}}{\textit{Duration of Observation in Minutes}} \tag{4}$$

$$\textit{Control Rate} = \frac{\#\ \textit{of turns coded as Control}}{\textit{Duration of Observation in Minutes}} \tag{5}$$

5. Results

Overall, metacognitive regulation activities were observed at a rate of about 5.25 observed behaviors per minutes (bpm) (Fig. 2). Metacognitive regulation was focused on the area of monitoring (3.6 bpm). The remainder of metacognitive regulation discussion was spent between planning (0.61 bpm) and evaluation (0.74 bpm), with minimal discussion or behavior related to control activities (0.31 bpm). To better understand how the students engaged in

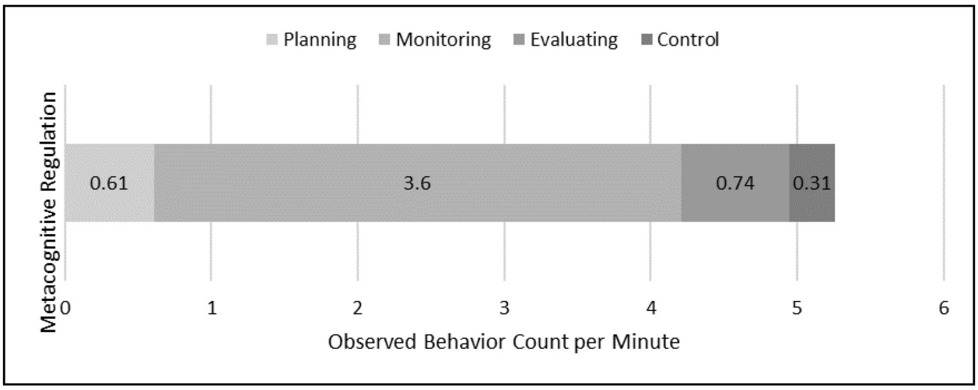


Fig. 2. Metacognitive regulation habits of all study groups over academic period.

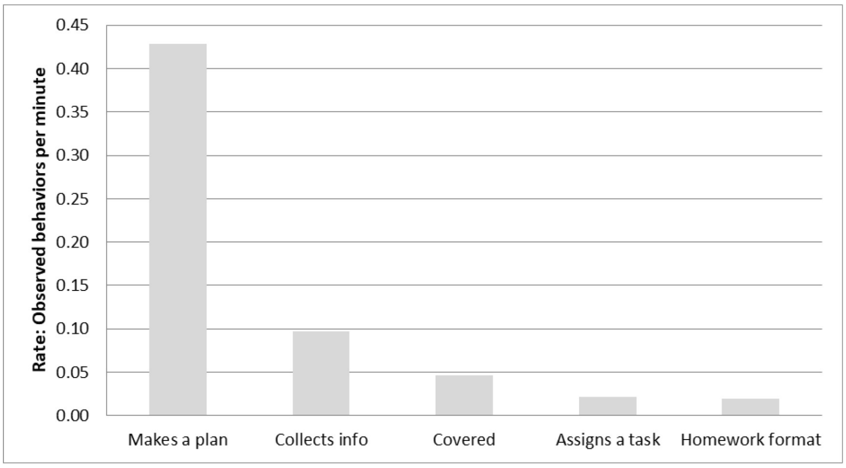


Fig. 3. Activities associated with MR – Planning.

each one of these metacognitive areas, the subcode level was evaluated to understand what actions made up each of these metacognitive areas.

5.1 Planning

In general, participants held discussions on making a plan at a higher rate than they discussed the current plan or the homework format when studying together (Fig. 3).

5.1.1 Makes a Plan

A 'makes a plan' action occurred when one or multiple participants talked about making a plan to accomplish a goal or complete a task. These conversations were sometimes very detailed in construction and involved multiple steps. For example, when developing a plan for completing part of a homework problem, Benjamin states, "Umm . . . I mean . . . yeah, we . . . we could add up all of the masses for fruit, sugar, and pectin and therefore solve for how much water is leaving. Although I guess we don't really have to do that." In this example, Benjamin creates a step-by-step plan for how to solve for how much water is leaving the system.

Other times, very general plans were made in order to complete a task. For instance, when discussing a plan to solve a system of equations, William says, "Just put it in the . . . put it in the Maple [software program]." In this example, William provides a plan of putting all the equations in Maple in order to solve the system of equations for the homework assignment. William does not provide a step-by-step plan of how to input the equations into Maple but instead provides the general plan to use Maple to solve the system.

5.1.2 Collects Information

During the planning process, participants engaged in collection actions in order to collect information and resources needed to accomplish their goals. Information was collected in order to determine how the planning process should be approached. For instance, at the beginning of a study session Benjamin asks, "Alright, so what's number 7?" Benjamin was seeking information to understand what the problem assigned entailed in order to start the planning process. Resources were also collected that were needed to successfully complete the task. Resources included things like books and notes (Jenny: "Ok. Let me grab my book."; Michael: "Maybe, did he [professor] post an example yet?") as well as fully worked solutions or answers (Chris: "We need someone else's answers."; William: "3.37. I'm gonna see if [student name] has it.").

5.1.3 Covered

Students had discussions related to what information or concepts might be covered on an upcoming exam. These discussions typically surrounded what topics were to be covered on an exam so that a plan for studying could be developed. If participants did not believe that information would be covered on an exam, they typically did not put that information in their plan for further study. For example, on an evening when studying for an upcoming exam was the group's primary focus, the group focused a significant amount of time creating the sheet of notes they were allowed to take in with them to the exam. During that preparation time, Michael asked, "We don't have anything with rotation, right?" in order to determine if he needed to put rotational equations on his equations sheet.

5.1.4 Assigns a Task

Assigning a task typically occurred when one student started asking other students to take on certain parts of the established plan. In one example, Wilson and Chris were working on a homework problem and Wilson realized that there may be two different ways to solve that particular problem. Wilson then says to Chris, "Chris, you do it your way and I'll do it my way. We'll see if we get the same answer." Wilson assigns Chris the task of taking one approach while Wilson will take the alternate approach to determine if both approaches reach the same end.

5.1.5 Homework Format

For the PSH course, students were required to submit all homework assignments using a specific homework format. An example of this homework format is shown in Fig. 4. The homework format required students to state information that was known from the problem statement, write an explanation of what information was to be found, draw a picture or system diagram of given information, and then provide an explanation of the strategy that is used in approaching the problem. By requiring students to use this homework format, the instructors of this course were providing a structure for students to plan out their homework problems.

Early observations recorded discussions of how to follow the homework format as students adjusted to engaging in this formal planning process. For example, at the beginning of one study session, OFF reminded each other of the components of the homework format. William asks, "What do we have to write? The find. The given. . ." As the academic term progressed, discussions of the homework format diminished as this process became more automatic.

5.1.6 Sets Goals and Targets

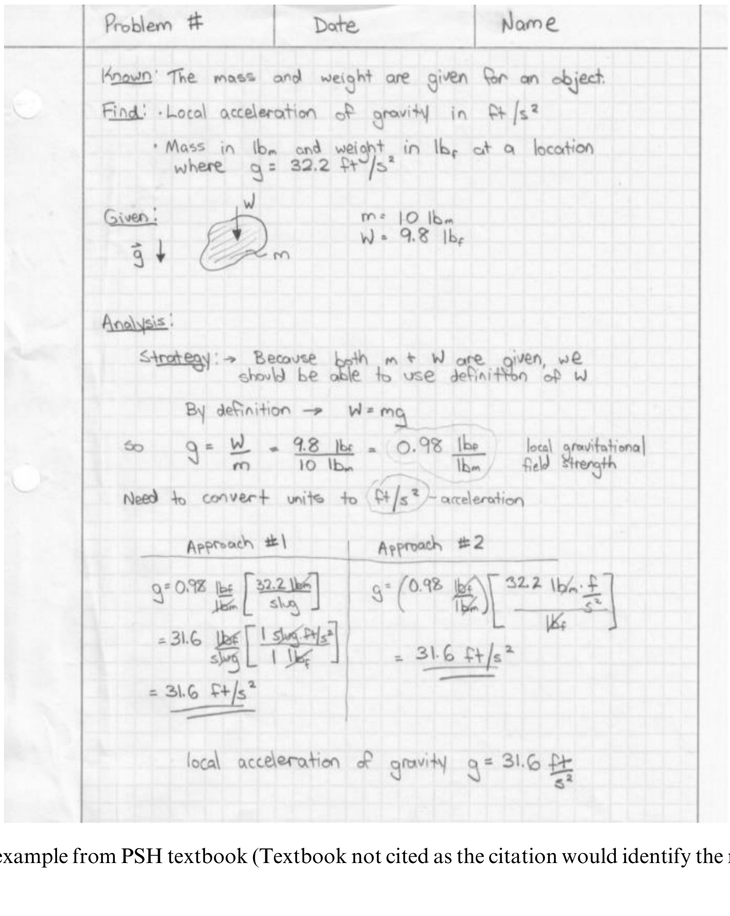
We observed no instances where participants were setting goals for the study session or the course.

5.2 Monitoring

Overall, participants check strategies or answers with one another at a higher rate than commenting on memory retrieval or mental clarity when studying together (Fig. 5).

5.2.1 Checks Strategy

Many times, participants had an idea about what strategy that they should attempt to use to solve part of a problem for a homework assignment. Still, when there was doubt about the appropriate strategy to implement, a participant might ask another study group member if that strategy was the correct one to solve the problem. While knowledge of the strategy to use is also a part of the metacognition model, this checking process is what is called *checks strategy*. For example, as Michael starts a problem,


Problem # | Date | Name

Known: The mass and weight are given for an object.

Find: · Local acceleration of gravity in ft/s²

· Mass in lb_m and weight in lb_f at a location where $g = 32.2$ ft/s²

Given: $\vec{g}\downarrow$ W m $m = 10\ lb_m$, $W = 9.8\ lb_f$

Analysis:

Strategy: → Because both m + W are given, we should be able to use definition of W

By definition → $W = mg$

So $g = \frac{W}{m} = \frac{9.8\ lb_f}{10\ lb_m} = 0.98\ \frac{lb_f}{lb_m}$ local gravitational field strength

Need to convert units to ft/s² – acceleration

Approach #1

$g = 0.98\ \frac{lb_f}{lb_m}\left[\frac{32.2\ lb_m}{slug}\right]$

$= 31.6\ \frac{lb_f}{slug}\left[\frac{1\ slug\ ft/s^2}{1\ lb_f}\right]$

$= 31.6$ ft/s²

Approach #2

$g = \left(0.98\ \frac{lb_f}{lb_m}\right)\left[\frac{32.2\ lb_m \cdot \frac{ft}{s^2}}{lb_f}\right]$

$= 31.6$ ft/s²

local acceleration of gravity $g = 31.6\ \frac{ft}{s^2}$

Fig. 4. Homework format example from PSH textbook (Textbook not cited as the citation would identify the research site for this study).

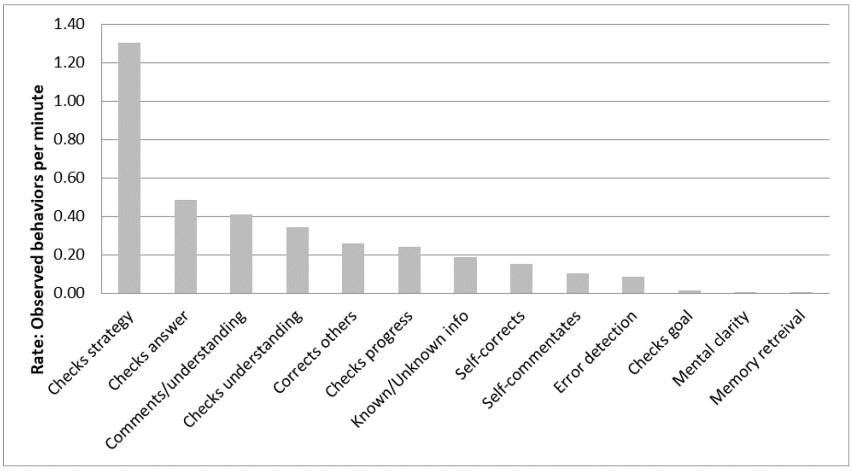


Fig. 5. Activities associated with MR – Monitoring.

he asks Benjamin, "So, mass flow rate is, well m1 equals 1000 kilograms per hour, right?" Michael thinks that the first mass flow rate in the problem should equal 1000 kilograms per hour but is hesitant. So, he checks this idea or strategy with Benjamin before proceeding with the problem.

5.2.2 Checks Answer

Participants frequently engaged in the practice of checking a final answer or intermediate answer with another member of the group. Participants checked answers to determine if they had successfully completed part of the task in order to move on to another segment. For example, when finishing a problem that they were working on, Wilson asks Chris, "Did you get 0.109%?" While this activity may sound evaluatory in nature because the check occurs at the end of solving a problem, this process is indeed a monitoring activity. In the same interaction, Wilson finishes the statement by saying, "Did you get 0.109%? Chris, our numbers don't match up." The process of checking the answer leads Wilson to make the evaluatory statement that Wilson and Chris had not successfully completed the problem because they did not achieve matching answers. The monitoring process of checking answers led Wilson to an evaluation statement, causing Wilson and Chris to return to the process of monitoring in order to find the mistake that occurred.

5.2.3 Comments/Understanding

In the process of working on a homework problem or listening to the explanation of a certain concept, many times participants would reach a point where they knew that they understood or did not understand the discussion that was occurring. For example, while looking at a fully worked homework solution from another student, William states, "I don't understand what [student]'s doing, exactly." Later in the same observation, as William listens to an explanation from David about a particular procedure, William says, "I understand you now David." These comments on understanding signal that either the participant can move on because understanding has been reached or the participant needs to pause and find more help because understanding has not been achieved.

5.2.4 Checks Understanding

In order to reach a point where a participant can determine if they (or another study group member) understands or does not understand, sometimes a participant may check their own understanding or the understanding of another group member by asking a question. For example, when Jenny begins to describe her process of coming to a solution, she says, "That's what I have . . . nine thirty . . . nine thirty eight . . . divided by 2032.5. Times 100 is 46.2." Benjamin then asks "Nine thirty eight divided by what?" Benjamin asks this question in order to check Jenny's understanding of what exactly she included in her calculations. From this question, Jenny realizes that she has transposed numbers and that is the mistake in her calculation. Participants may also check their understanding in order to ask for clarification about a topic or strategy.

5.2.5 Corrects Others

While discussing specific strategies that had been used, participants often engaged in the process of correcting others. Participants corrected others by showing them a step in their process or strategy that was incorrect or would not successfully complete the task. For instance, when working with David on a species accounting problem, William finds that David has not properly labeled all of his variables in one of his equations. So William points out "Two . . . there should be another two in here." David sees the mistake and then fixes his equation.

5.2.6 *Checks Progress*

In order to stay on track toward the progress of completing assignments or to determine if help might be available, participants would check on their own progress or on the progress of other study group members. For example, Terry asks, "Are you guys drawing your systems or what?" A few turns later, Terry asks "What's our system?" By asking if others had drawn their systems, Terry was able to ask for help from those who had already accomplished the task. When checking progress, the participant is focused on checking and identifying at what point in completing the task at hand they or another group member are in.

5.2.7 *Known/Unknown Information*

During the process of solving a problem, participants sometimes needed to check back to be reminded of what information was given in a problem statement and what information was not provided. At times, this checking process impacted the direction taken by the study group members when solving a problem, while at other times a direction or path was confirmed through this checking process. For example, while working on a problem dealing with conservation mass, Adam asks if others in the group are assuming that the system is at steady state to which David responds, "Yeah, it said it in the problem." By checking back to the information in the problem statement David confirmed to Adam that the approach he was taking was the appropriate strategy because of the fact that the system in question was operating at steady state. If that information had not been given in the problem or if the study group members had not gleaned that information from the problem statement, Adam would have potentially changed the strategy that he was using to solve this problem.

5.2.8 *Self-corrects*

While many participants engaged in the practice of correcting other group members, they also engaged in the practice of correcting themselves when a mistake was detected. In the case of self-corrects, an individual realizes that a mistake has occurred and has an implementable strategy for correcting the mistake. For example, as Michael checks an answer with Benjamin he states, "I got fifty five. Oh shoot, that's not right, that's not right. Wrong number." Michael proceeds to fix the "wrong number" and achieve an answer match with Benjamin.

5.2.9 *Self-commentates*

In contrast to other collaborative practices described thus far, the process of self-commentating is strictly an individual behavior that participants engage in to support their own monitoring activities. When a participant self-commentates, they verbalize the mental thought process they are engaged in. Self-commentating supports cognitive activity as it helps the participant keep track of the process they are engaged differently than when they keep these processes as internal thoughts. For example, as LIB works on a homework problem one evening, Michael and Jenny finish up a discussion about a portion of the assignment. Michael then begins to speak quietly to himself and makes the following comment:

> "So dmsys over dt goes out, zero steady state (crossing out terms on paper) equals the sum of mass flow minus the sum of mass flow. So the sum of mass flow in equals the sum of mass flow out. So we have 1000 kilgrams per hours plus 1.3 times 1000. (inaudible)."

In this example, as Michael begins to work individually, he verbalizes the steps he is engaging in. He likely verbalizes his steps in an effort to help himself keep track of what he is doing, thus engaging in a monitoring process.

5.2.10 *Error Detection*

Many participants engaged in correcting themselves and others during study group sessions. Error detection identifies that a mistake has occurred but lacks a clear plan to correct the mistake. When correcting self or others, participants detected an error and had a viable alternative solution to offer in place of the incorrect strategy attempted. While many times viable alternative solutions were available, there were times where participants realized there was some sort of mistake in a strategy or solution but did not know exactly what the mistake was or how to correct it. In these cases, an error was detected without a clear plan for correction. For example, when Jenny attempts to check a strategy with Benjamin, she realizes that the strategies are not matching up and states, "Wait, what? I put something down wrong."

5.2.11 *Checks Goal*

In order to ensure that the study group was making progress towards the correct goal, participants would check back to the intended goal of a problem. This ensured that study groups were not straying in developing their strategy for a solution. For example, as Michael discusses a strategy he wants to pursue on a homework problem, he stops, leans over to check Jenny's paper and asks, "What are we finding?" When he receives an answer, he continues developing his strategy to solve the problem. In this example, Michael took a pause from making progress on developing a strategy in order to determine if he was moving in the direction of the goal for this particular problem. Michael had to make sure that he knew what he was solving for before he could continue developing his strategy. When checking a goal, participants are focused on referring back to the original goal or set of goals developed for a specific task.

5.2.12 Mental Clarity

At times, participants would realize that they were having problems concentrating or focusing on the task at hand. By commenting on mental clarity, participants were monitoring their mental state. For example, Jenny stated that she was very happy that another group member was very focused that evening "Cause I'm finding it a little hard to concentrate."

5.2.13 Memory Retrieval

Though not prominent in the data, some participants would share when they were attempting to recall information that had been discussed at alternate times by other group members or instructors. For example, when trying to recall information the instructor had given on a particular homework assignment, Benjamin stated, "I'm trying to remember what he said about that."

5.3 Evaluation

For evaluation behaviors, participants discussed their *progress* on certain tasks at a higher rate than the *reasonableness* of a solution or strategy when studying together (Fig. 6). Note that a major difference between many monitoring and evaluation strategies is whether a participant is seeking information or is making a conclusion. For monitoring behaviors, participants tend to focus on seeking some sort of information in order to determine if they are on track towards a goal. In contrast, evaluation behaviors focus more on displaying that a determination has been made that the goal has been achieved to some standard. Evaluation behaviors tend to focus more on the result of achieving the goal and whether the process for achieving the goal was appropriate, effective, and efficient.

5.3.1 Progress

Participants spent a significant amount of discussion time evaluating their progress toward a goal or in completing a task. Commenting on progress provides an estimate of how close or far a participant or group is to reaching a goal or provides evidence that a goal has been achieved. For example, while working on a homework problem Chris asked Wilson if he had finished writing down the homework problem. Wilson responded by saying, "I'm working on it." In this example, Wilson evaluates by commenting on the progress that he has made in writing down the problem. It should be noted that Chris engaged in a monitoring strategy of 'checking progress' by asking Wilson if he had written down the problem.

While many times comments of progress were meant to provide a marker towards how close a participant was to completion, there were instances where comments of progress were celebratory in nature. For example, as he completed a problem, David exclaimed "Yes! Adam, look. I did one!" In this case, the comment of progress from David was to show that he had completed a certain task.

5.3.2 Correctness/Accuracy

Participants also engaged in evaluation behaviors by discussing the correctness or accuracy of an answer or strategy. One way correctness or accu-

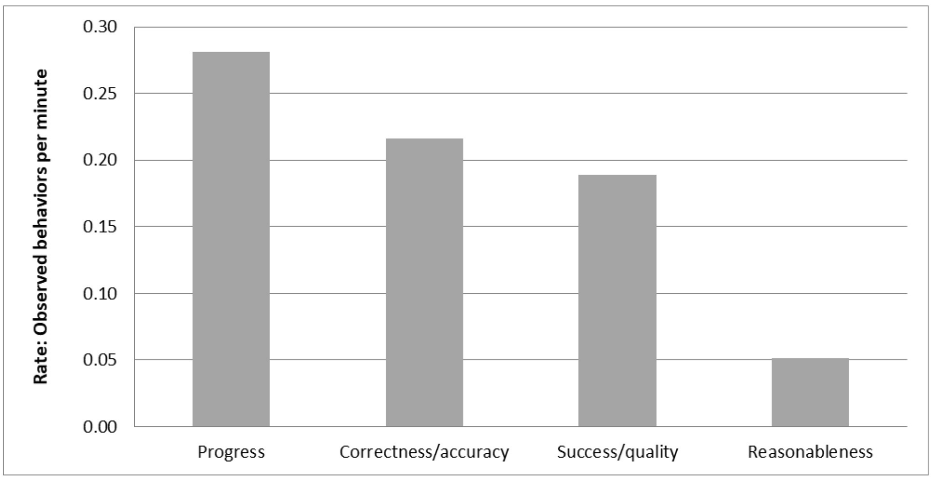


Fig. 6. Activities associated with MR – Evaluation.

racy were signified was by responding positively or negatively to questions regarding a check of a strategy or answer. For example, Jenny asks the question, "So, then for the sugar solution we do 1.3 times 1000 . . ." to which Benjamin responds, "Mhmm." This positive response indicates that the strategy that Jenny has suggested is in fact correct. Another way in which participants discussed correctness or accuracy were in statements made about whether a strategy produces a desired or expected outcome. For example, as Chris works on a unit conversion for a problem he states, "Hmm. Kelvins doesn't cancel out the way it's supposed to." In this statement, there is an expected outcome that the unit, Kelvin, will cancel out in a certain way. The strategy that Chris used does not produce this outcome and is therefore deemed to be incorrect.

5.3.3 Success/Quality

Another way in which participants engaged in evaluation behavior was through discussions of success or quality. These comments are not directly tied to discussions of whether an answer or strategy is correct or accurate. Instead, they infer that a certain strategy or answer is successful at reaching some goal, though the intended goal is typically not correctness or accuracy. For example, after finding an answer to a homework problem, Wilson looks at Chris's paper and states, "Our numbers aren't matching up." In this case, there is an evaluation of not reaching success, but this statement in not measured against a correct standard. Instead of the goal being to reach the correct answer, the goal was to reach matching answers. Jenny makes a similar statement during a different observation when she says to her group, "Ok, I got a much different number than you."

5.3.4 Reasonableness

Evaluation also occurred when the participants discussed the reasonableness of a certain answer achieved. Statements of reasonableness typically showed that answers achieved were out of the range of what the participant expected. For example, Michael states "That's really, really, really, really fast" and then "That's not realistic." At another point in the same observation, as Becca discusses the units for a particular answer, Becca states "Kilowatts. That's reasonable." Comments of reasonableness predominantly showed no explicit sign of justification for why an answer was or was not reasonable.

There were times when participants wanted to make evaluations of the reasonableness of answers but discussed how they did not have all the information necessary to make a reasonableness judgement. For example, when working on a homework problem involving a jet engine, Becca attempted to make reasonableness judgments but was aware of her lack of knowledge that inhibited her ability to make a reasonableness judgment:

> Becca: "So, when you do this timesing by a thousand...cause I think you have to . . . like cause your units do not cancel out unless you times by a thousand in there. Somewhere. And when you do that, that's when you get a huge velocity."
>
> Benjamin: "Ok. But it is a jet engine so . . ."
>
> Becca: "Is that like a reasonable . . ."
>
> Benjamin: "That's a very reasonable velocity."
>
> Becca: "Oh, it is?"
>
> Benjamin: "Yeah."
>
> Becca: "So, I'm not crazy."
>
> Benjamin: "No."
>
> Becca: "See, if I had just known that could be a reasonable velocity . . ."
>
> Jenny: "Well, also you could have saved it and asked [professor]. If for anything else, that would take two seconds."
>
> Becca: "Yeah, except that it, you use that for every other calculation. So . . ."
>
> Jenny: "It's really easy to do it and like change the one number."
>
> Benjamin: "Ok, so then . . ."
>
> Becca: "So that is a reasonable number for a jet engine?"
>
> Benjamin: "Yeah."
>
> Becca: "I don't know things like this. Make sure you get the same number as me."

In this example, Becca discusses how she had difficulty determining if the answer she calculated for the homework problem was reasonable because she did not know enough about jet engines. Benjamin, who had more knowledge of jet engine speeds, told Becca that her answer was, in fact, reasonable. Becca's lack of knowledge about jet engines, and not her lack of metacognitive skill in evaluation, led to her inability to make a reasonableness judgment in this case. If Becca had been given information about the normal speeds of jet engines, she may have been able to engage in a reasonableness behavior that would have helped her determine if she had reached the goal of adequately solving the homework problem.

5.4 Control

In general, participants showed evidence of *changing strategies* or *asked for help from others* at a higher rate than *referring to representations* or *repeating strategies* when studying together (Fig. 7).

5.4.1 Changes Strategy

Participants engaged in a control strategy when

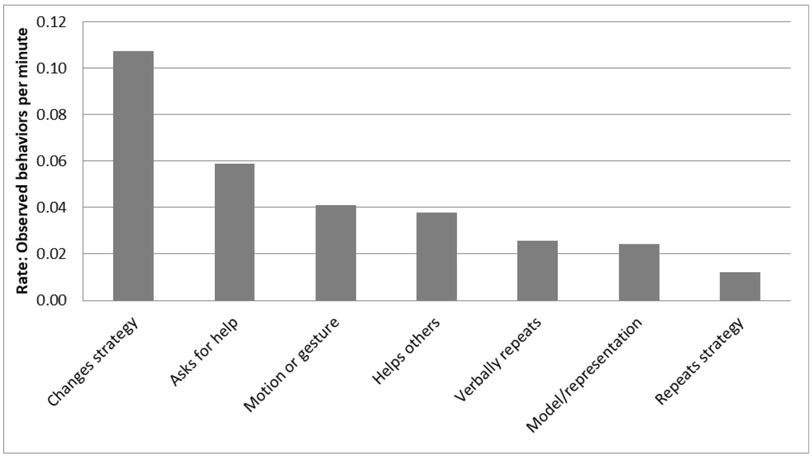


Fig. 7. Activities associated with MR – Control.

they showed evidence of changing a strategy because of some sort of monitoring activity. A change in strategy was most notably shown when a participant would erase something (an equation, variable, or diagram) from their paper and write something new. This action was more of a non-verbal action though it could sometimes be connected to a verbal response by a participant.

5.4.2 Asks for Help

Another control strategy occurred when one participant would ask for the help of another participant. A request for help typically occurred when a participant determined that there was an error in their current strategy or found that the answer they achieved did not match the answer of another in the group. For example, when Jenny asks Benjamin what he got for an answer and finds that their answers do match, she says "Ok, so I need to see what you changed because I have negative seven thousand two hundred and fifty point nine. (Takes Benjamin's paper) Ok."

5.4.3 Motion or Gesture

A non-verbal motion or gesture can signify that a participant is engaging in a control strategy. For a motion to be considered a control strategy, it should be used in order to support the cognitive activity of a participant. For example, when Michael is working through a problem involving canceling out certain factors and taking into account geometry, the following happens: "The x-components cancel out (moving hands opposite from one another) in each direction so they have both y's going down. So you just do what the fifteen times . . . (uses hands like he is measuring geometry)." In both cases, Michael uses his hands to represent a motion that aids his understanding of what he is talking about.

5.4.4 Helps Others

While many times participants look for help from others, at other times participants also offer help to others. This offer of help shows a need for a change in strategy just as a request for help shows a need for change. For example, Michael offers help to Jenny by saying "Let me see this (takes Jenny's paper)." Michael takes Jenny's paper in order to find the mistake that Jenny believes she has in her strategy.

5.4.5 Verbally Repeats

The purpose of verbally repeating a strategy is to determine if a word, phrase, or strategy was understood by an individual or the group. Some participants would verbally repeat themselves in order to check comprehension. This process was done both individually and collaboratively, meaning sometimes a participant would repeat a phrase to themselves to check their own comprehension while other times a participant may repeat a phrase to check the understanding of others in the group. For example, Jenny was checking an answer she obtained with Benjamin and Michael, but the answers between the three were not matching. Michael found that Jenny was transposing a number, which was causing an incorrect calculation. In order to make sure that she was correct, Jenny repeated the series of numbers out loud, "Two three zero two. Goodness gracious team."

5.4.6 Model/Representation

Participants also created and used models and representations in order to support their cognitive activity while working toward completing tasks. The representations included graphical pictures of systems or a series of equations located to a common space. The whiteboard was a popular place for LIB to create representations that were used by the group. Different group members would take turns drawing pictures or writing equations on the board that were used to explain different parts of the task. The pictures and equations were typically left on the whiteboard for a period of time so that they could be used for reference later in the study group session.

5.4.7 Repeats Strategy

At times, participants felt the need to repeat a strategy (either verbally, on paper, or on the calculator or computer) in order to determine if the task had been successfully completed or if understanding had been reached. For example, when Jenny and Benjamin do not agree on the final answer to a problem, Jenny says "Let me redo my calculations really fast (punches numbers in calculator)." Jenny repeats her strategy in order to determine if she had made a mistake in her calculations.

6. Discussion

The results of this research provide two important findings regarding the metacognitive regulation behaviors of engineering students in naturalistic settings. First, monitoring was the most frequent regulation behavior. Second, within the four categories of metacognitive regulation (planning, monitoring, evaluation, and control) behaviors occurred and different frequencies (e.g., more evaluating time to completion and less evaluating reasonableness of the solution) and some anticipated behaviors were not observed (stating goals). These findings support and expand literature within engineering education and education more broadly.

6.1 A Picture of Metacognition in Engineering

The current study aligns well with the few previous studies of metacognition yet expands prior results. For example, Litzinger et al. [11] found that metacognition plays an important role in how well students problem solve in statics specifically that participants engaged in more monitoring behaviors than evaluation behaviors while thinking aloud in solving statics problems. In our study and theirs, monitoring activities were identified as the majority activity in metacognitive regulation. However, Litzinger et al. only investigated engagement in monitoring and evaluation activities unlike our study which included planning and control as part of metacognitive regulation thus providing a more complete picture of metacognitive regulation

Case, Gunstone, and Lewis [33] have also explored the metacognitive development of engineering students in a chemical engineering course. Case et al. found that students initially focused their original metacognitive skills on discipline, time management, and discussing task difficulties. Case et al. found that over time engineering students moved away from time-management tasks and moved closer to a final state of selecting strategies and resources in order to meet learning objectives. When comparing the initial state of participants that Case et al. observed in their study to the observed state of participants in our study, similarities between the two groups were found and included significant mental resources dedicated towards checking progress against time standards and discussing task difficulty. As evidenced in the current study's analysis of evaluation strategies, participants focused more evaluation discussion on commenting on progress, specifically in terms of the time duration to complete assignments. Participants spent less time focused on their quality or success of reaching learning objectives. This may be due in part to the fact that students were not required to report their own assessment of their learning as part of the PSH course structure which research shows is important. For example, Morgan [34] found that students who monitored or evaluated their progress based on time or duration to complete an assignment while studying did not significantly improve their end of course examination scores. Instead, students who monitored or evaluated their progress based on defined learning objectives did significantly improve their end of course examination scores.

The results of this study also inform a significant gap in current literature in the area of what students are not doing. For instance, the current study found that students engage in evaluation strategies that look at the reasonableness of solutions at a lower rate than evaluation strategies that focus on estimates of time to completion. One reason for a lack of focus on reasonableness in evaluation could be due to the fact that students do not have adequate previous knowledge about the context of problems given for assignments or examinations. If the context of a problem is not one that students have experienced before, this may limit their ability to determine if an answer is reasonable or not [35]. Therefore, as educational practitioners, we must either select problem contexts that are familiar to our students or provide them with the resources needed to make reasonableness judgments. This finding is specifically applicable to the PSH course from STFC. Because the textbook for the PSH course was written by instructors from STFC, the homework assignments were also written by the instructors. Some of the homework problems were written in a way that the context of the problem was specific to STFC (e.g., using the pond on campus as the context for a conservation of mass problem). While contexts such as these were more relatable to all students at STFC, other contexts, such as problems about jet engines, were only relatable to students who had experience or knowledge with jet engines or the aerospace industry. As shown in the example between Becca and Benjamin, Becca did not have experience with jet engines and thus did not have the prior knowledge necessary to make a reasonableness judgment in that context. Becca would have benefited from supplemental materials that helped her learn about the normal operating conditions of jet engines in order to make an appropriate reasonableness judgment.

We also found that, under the category of planning, students did not explicitly state the goals that they had for a study session or task. As noted in the background literature, Davidson and Sternberg [5] indicate goals as central to problem solving. Although goals can be defined and described in many ways, achievement goals is a useful framework for thinking about why goal setting is important. Achievement goals are defined as the general goals that students have in regard to the tasks that they are engaging in and are generally viewed in two orientations: mastery and performance [36]. Mastery goals are generally focused on learning and understanding while performance goals are generally focused on demonstrating one's abilities. Vrugt and Oort Vrugt and Oort [37] found a positive relationship between mastery goal orientation and high engagement in metacognitive strategies. Though participants in the current study did not explicitly state goals, they did engage in monitoring by checking back to goals. This implies that students do set goals for themselves and, potentially, their study groups as they prepare to work though they are not outwardly articulating goals.

6.2 A Picture of Metacognitive Engagement in General Education

The specific metacognitive behaviors identified in this study builds upon and expands the work of researchers such as Whitebread [19, 20, 38], Bryce [39], Volet [32, 40], and Rogat [41]. These researchers have approached the task of qualitatively exploring the metacognitive behaviors of different populations in order to better understand how people engage in these habits. While research in the area of qualitative descriptions of metacognition is minimal, researchers are beginning to develop an understanding of what metacognition looks like at different stages of development as well as in different contexts and content areas. For example, information exists on the metacognitive habits of young children (Whitebread), middle school children (Rogat), undergraduate veterinary students (Volet), and now undergraduate engineering students (McCord). The field of observational studies on metacognitive engagement is quite small and needs further expansion to better understand how metacognitive behaviors may be linked at different developmental stages as well as in different contexts and content areas. The current study contributes to this area in providing a second look at metacognition in an undergraduate context (i.e., veterinary medicine and now engineering) and with a different focus; Volet's which focused on metacognitive behaviors in naturalistic settings. Future work can begin to compare metacognitive engagement in these two content areas to determine if certain disciplines require different metacognitive skills. Because of the controversial nature of whether metacognitive skills are domain-general or domain-specific, it is important for the research community to continue its focus on understanding how generalizable these skills may be with different tasks or content areas.

The prominence of metacognitive regulation in this study aligns with the focus in education on pedagogical development on developing metacognitive regulatory skills. Previous pedagogical approaches that were intentionally created to develop metacognitive skills have focused on developing metacognitive regulation skills like planning, monitoring, evaluation, and control as opposed to developing metacognitive knowledge [e.g., [42, 43]] . In the context of the PSH course in this the current study, components of the course design focused on engaging students in planning and monitoring activities. These components included a homework format and a standard form of the accounting principle that would help students plan their problem solving process. The use of the 4 Q's from the course textbook potentially supported engagement in monitoring activities. It is possible that students engage in more regulation activities because pedagogies have focused more on developing these skills and less on developing metacognitive knowledge. Because of the fact that metacognitive knowledge is also important in learning, can be accurate or inaccurate, and can be very resistant to change [16], future work should focus on developing pedagogical interventions with the purpose of building accurate metacognitive knowledge. One example of a pedagogical intervention created for the purpose of developing accurate metacognitive knowledge in students comes from the field of language studies. With this pedagogical approach, developed by Cotterall and Murray [44], students are engaged in working directly with language materials, instruction is provided on learning strategies, students keep portfolios of their work, and final grades are determined through a collaborative evaluation process that includes self-assessment activities.

The portfolio and self-assessment activities are designed specifically to develop accurate metacognitive knowledge of the learner by engaging them in reflective activities that ask the learner to review their level of understanding and skill on a frequent basis.

6.3 Limitations and Future Work

This study described the observed metacognitive behaviors of engineering students working on well-structured engineering problems. The results of this study might be limited due to the selection of the context for the observations. By broadening the pool for observations, the results of this study could be strengths and generalized over a larger population. For example, this study was conducted among students engaged in well-structured engineering problems in a lower level engineering course. Well-structured problem solving represents some but not all of the problem solving activities undergraduate students will engage in during their studies. Future work should expand into learning contexts that engage students in ill-structured problems, such as senior capstone design courses. In these courses, students are engaged in ill-structured problem solving where industry and community projects are given to senior teams to investigate and develop a solution ready for implementation. No specific solution is expected thus potentially requiring different metacognitive skills than well-structured problem solving, where a single solution or process is typically expected. Senior capstone designs closely reflect the type of problem solving engineers will engage in once they transition to industry positions.

This study was also conducted in a sophomore level engineering course, which limits the translatability of the observed behaviors to one development stage in the growth of aspiring engineers. Future research should focus on observation behavior at multiple times across the undergraduate curriculum. These observations can contribute to an understanding of how metacognitive skill develops throughout the undergraduate engineering process. Further, observations of practicing engineers could contribute to an understanding of the goal for metacognitive development in undergraduate curricula.

Finally, the sample population for this study was homogenous in terms of gender, race, discipline, institutional structure and geographical location. In order to determine translatability of metacognitive skill in engineering, future research should focus on expanding out to more diverse populations.

7. Conclusions

Metacognition is a critical skill needed for learning in engineering. Observations of participants in self-moderated learning environments showed a number of different metacognitive behaviors utilized at different rates and for different purposes. Participants engaged in monitoring behaviors at a higher rate than planning, evaluating, and control behaviors. While several planning behaviors were observed, explicit goal setting activities were not observed during the course of observations, though behaviors related to goals set by individuals or the study group were observed. This could highlight that students implicitly set goals without sharing with those they are working with. These implicit goals could lead to frustration due to conflicting, unspoken goals by different members of the group. Discussions surrounding the reasonableness of solutions was also minimally observed during observations. While determining the reasonableness of solutions is an important skill in the field of engineering, little attention is given to teaching students how to determine reasonableness. Students may like prior knowledge in the problem context, making it difficult for students to engage in reasonableness judgements.

This paper provides in-depth rich descriptions of metacognitive regulation behaviors used by sophomore engineering students while studying and working on homework in a mechanical engineering problem-solving course. This work gives a baseline for the types of behaviors students currently use. From this work, instructors can design metacognitive interventions for developing students' skills for use during self-study. Future work should include understanding the metacognitive abilities of students through the undergraduate curriculum.

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References

1. D. H. Jonassen, Toward a design theory of problem solving, *Educational technology research and development*, **48**(4), pp. 63–85, 2000.
2. M. T. H. Chi, M. Bassok, M. W. Lewis, P. Reimann and R. Glaser, Self-Explanations: How Students Study and Use Examples in Learning to Solve Problems, *Cognitive Science*, **13**(2), pp. 145–182, 1989.

3. N. E. Perry, Introduction: Using Qualitative Methods to Enrich Understandings of Self-Regulated Learning, *Educational psychologist*, **37**(1), pp. 1–3, 2002.
4. R. L. Dominowski, Verbalization and Problem Solving, in *Metacognition in Educational Theory and Practice*, D. J. Hacker, J. Dunlosky and A. C. Graesser, (eds), Lawrence Erlbaum Associates, Publishers, Mahwah, New Jersey, pp. 25–46, 1998.
5. J. E. Davidson and R. J. Sternberg, Smart Problem Solving: How Metacognition Helps, in *Metacognition in Educational Theory and Practice*, D. J. Hacker, J. Dunlosky and A. C. Graesser, (eds), Lawrence Erlbaum Associates, Publishers, Mahwah, New Jersey, pp. 47–68, 1998.
6. J. Larkin, J. McDermott, D. P. Simon, and H. A. Simon, Expert and Novice Performance in Solving Physics Problems, *Science*, **208**(4450), pp. 1335–1342, 1980.
7. J. R. Hayes, *The complete problem solver*, Hillsdale, N.J., L. Earlbaum Associates, 1989.
8. D. H. Jonassen, Research issues in problem solving, in *11th International Conference on Education Research*, Seoul, Korea, 2010.
9. D. H. Jonassen, J. Strobel and C. B. Lee, Everyday problem solving in engineering: Lessons for engineering educators, *Journal of Engineering Education*, **95**(2), pp. 139–151, 2006.
10. S. Sheppard, A. Colby, K. Macatangay and W. Sullivan, What is engineering practice?, *International Journal of Engineering Education*, **22**(3), p. 429, 2007.
11. T. A. Litzinger, P. V. Meter, C. M. Firetto, L. J. Passmore, C. B. Masters, S. R. Turns, G. L. Gray, F. Costanzo and S. E. Zappe, A Cognitive Study of Problem Solving in Statics, *Journal of Engineering Education*, **99**(4), pp. 337–353, 2010.
12. O. Lawanto, Students' metacognition during an engineering design project, *Performance Improvement Quarterly*, **23**(2), pp. 117–136, 2010.
13. O. Lawanto, D. Butler, S. Cartier, H. B. Santoso and W. H. Goodridge, Task interpretation, cognitive, and metacognitive strategies of higher and lower performers in an engineering design project: an exploratory study of college freshmen, *International Journal of Engineering Education*, **29**(2), p. 459, 2013.
14. J. H. Flavell, Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry, *American Psychologist*, **34**(10), pp. 906–911, 1979.
15. A. Brown, Metacognition, Executive Control, Self-Regulation and Other More Mysterious Mechanisms, in *Metacognition, Motivation and Understanding*, F. E. Weinert and R. H. Kluew, (eds), Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey, pp. 65–116, 1987.
16. M. V. J. Veenman, B. H. A. M. Van Hout-Wolters and P. Afflerbach, Metacognition and learning: conceptual and methodological considerations, *Metacognition and Learning*, **1**(1), pp. 3–14, 2006.
17. J. R. Baird, Improving learning through enhanced metacognition: a classroom study, *European Journal of Science Education*, **8**(3), pp. 263–282, 1986.
18. P. Tarricone, *The Taxonomy of Metacognition*, Psychology Press, p. 285, 2011.
19. D. Whitebread, P. Coltman, D. Pasternak, C. Sangster, V. Grau, S. Bingham, Q. Almeqdad and D. Demetriou, The development of two observational tools for assessing metacognition and self-regulated learning in young children, *Metacognition and Learning*, **4**(1), pp. 63–85, 2009.
20. D. Whitebread and D. Pino-Pasternak, Video analysis of self-regulated learning in social and naturalistic contexts, in *Interpersonal Regulation of Learning and Motivation: Methodological advance*, S. Volet and M. Vauras, (eds), Routlegde, Abingdon, Oxon, pp. 14–44, 2013.
21. P. H. Winne and A. F. Hadwin, Studying as Self-Regulated Learning, in *Metacognition in Educational Theory and Practice*, D. J. Hacker, J. Dunlosky and A. C. Graesser, (eds), Lawrence Erlbaum Associates, Publishers, Mahwah, New Jersey, pp. 277–304, 1998.
22. L. Nilson, *Creating Self-Regulated Learners: Strategies to Strengthen Students' Self-Awareness and Learning Skills*, Stylus Publishing, 2013.
23. R. McCord, Thinking About Thinking in Study Group: Studying Engineering Students' Metacognitive Engagement in Naturalistic Settings, in *Engineering Education*, Virginia Polytechnic Institute and State University, Blacksburg, VA. 2014.
24. J. P. Spradley, *Participant Observation*, New York, Holt, Rinehart and Winston, 1980.
25. G. B. Rossman and S. F. Rallis, *Learning in the field: an introduction to qualitative research*, Thousand Oaks, Calif., SAGE, 2012.
26. C. Glesne, *Becoming qualitative researchers: an introduction*, Boston, Pearson, 2011.
27. S. B. Merriam, What Can You Tell From an N of 1?: Issues of Validity and Reliability in Qualitative Research, *PAACE Journal of Lifelong Learning*, **4**, pp. 51–60, 1995.
28. C. E. Foor, S. E. Walden and D. A. Trytten, ''I wish that I belonged more in this whole engineering group:'' Achieving individual diversity, *Journal of Engineering Education*, **96**(2), pp. 103–115, 2007.
29. A. L. Pawley, Learning from small numbers: Studying ruling relations that gender and race the structure of US engineering education, *Journal of Engineering Education*, **108**(1), pp. 13–31, 2019.
30. R. E. McCord and H. M. Matusovich, Naturalistic observations of metacognition in engineering: Using observational methods to study metacognitive engagement in engineering, *Journal of Engineering Education*, **108**(4), pp. 481–502, 2019.
31. J. A. Maxwell, Using Numbers in Qualitative Research, *Qualitative Inquiry*, **16**(6), pp. 475–482, 2010.
32. S. Volet, M. Vauras, D. Khosa and T. Iiskala, Metacognitive regulation in collaborative learning, in *Interpersonal Regulation of Learning and Motivation*, S. Volet and M. Vauras, (eds), Routledge, Abingdon, Oxon, pp. 67–101, 2013.
33. J. Case, R. Gunstone and A. Lewis, Students' Metacognitive Development in an Innovative Second Year Chemical Engineering Course, *Research in Science Education*, **31**(3), pp. 313–335, 2001.
34. M. Morgan, Self-monitoring of attained subgoals in private study, *Journal of Educational Psychology*, **77**(6), pp. 623–630, 1985.
35. N. Shin, D. H. Jonassen and S. McGee, Predictors of well-structured and ill-structured problem solving in an astronomy simulation, *Journal of Research in Science Teaching*, **40**(1), pp. 6–33, 2003.
36. E. S. Elliott and C. S. Dweck, Goals: An approach to motivation and achievement, *Journal of Personality and Social Psychology*, **54**(1), pp. 5–12, 1988.
37. A. Vrugt and F. J. Oort, Metacognition, achievement goals, study strategies and academic achievement: pathways to achievement, *Metacognition and Learning*, **3**(2), pp. 123–146, 2008.

38. D. Whitebread, H. Anderson, P. Coltman, C. Page, D. P. Pasternak and S. Mehta, Developing independent learning in the early years, *Education 3–13*, **33**(1), pp. 40–50, 2005.
39. D. Bryce and D. Whitebread, The development of metacognitive skills: evidence from observational analysis of young children's behavior during problem-solving, *Metacognition and Learning*, **7**(3), pp. 197–217, 2012.
40. S. Volet, M. Vauras and P. Salonen, Self- and Social Regulation in Learning Contexts: An Integrative Perspective, *Educational Psychologist*, **44**(4), pp. 215–226, 2009.
41. T. K. Rogat and L. Linnenbrink-Garcia, Understanding quality variation in socially shared regulation: A focus on methodology, in *Interpersonal Regulation of Learning and Motivation: Methodological advances*, S. Volet and M. Vauras, (eds), Routledge, New York, NY, pp. 102–124, 2013.
42. V. W. DeLuca and N. Lari, Developing Students' Metacognitive Skills in a Data-Rich Environment, *Journal of STEM Education: Innovations and Research*, **14**(1), pp. 45–55, 2013.
43. M. Manke-Brady, "Clickers" and metacognition: How do electronic response devices ("clickers") influence student metacognition? University of Southern California, United States – California. p. 183. 2012.
44. S. Cotterall and G. Murray, Enhancing metacognitive knowledge: Structure, affordances and self, *System*, **37**(1), pp. 34–45, 2009.

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