WIP: Scaffolding Study Strategies in First-Year Engineering

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Work-in-Progress: Scaffolding Study Strategies in First-Year Engineering

I. Abstract

This WIP paper will describe the development of a pedagogical intervention to scaffold knowledge organization. To succeed academically, engineering students must develop a deep conceptual understanding of course topics and then apply this learning to solve complex problems. While experts know how to organize their knowledge, students often need support reflecting on the content and their learning. In this study, students in an over 500-person first-year engineering course were provided with a worksheet called the "Synthesis Sheet" that prompted them to organize declarative, procedural, conditional, and contextual knowledge on a topic. We investigated the efficacy of this intervention by examining student opinions of the intervention and how their resource engagement influenced their grades throughout the term. We found that students struggling in the course found the Synthesis Sheets more useful, and students who identified Synthesis Sheets as a part of their study process in the middle of the academic term performed up to half a letter grade better than their peers. Future studies will use a refined Synthesis Sheet based on student feedback, adjust post-exam reflections to gather more data on resource use, and further analyze links between conditional thinking and performance.

II. Motivation and background

Motivation

Metacognition served as the guiding framework for this study. Often described as being aware of one's thinking [1], metacognition involves the development of metacognitive knowledge, through which someone learns when, why, and how to apply information [2]. Metacognitive knowledge supports the development of metacognitive skills where students can self-regulate by planning, monitoring, and evaluating their learning [3].

To succeed academically, engineering students must develop effective study skills and become self-regulated learners capable of reflecting on their learning needs and taking action to improve their understanding and application of course topics [4]. In engineering, mastering and applying problem-solving heuristics (e.g., restating the problem, drawing diagrams, and identifying relevant formulas [5] [6]) is crucial for efficient problem-solving and academic performance [7] [8]. While experts typically know how to organize their knowledge to solve problems quickly, novices can struggle [9]. To succeed in their studies, students must develop a deep understanding of how problem-solving strategies function in the context of other class concepts and learn when to apply one strategy over another [10].

Research Context

At a private, mid-sized R1 institution, over 500 first-year students enroll in an introductory engineering course during their first quarter. This course covers MATLAB programming and linear algebra. Through this course, students are provided with ample resources to aid their learning, such as course materials, drop-in tutoring, and peer-guided study groups. The introductory subject matter and breadth of existing resources make this course an optimal entry point for introducing effective study strategies early in students' engineering education.

III. Study Design and Methods

Study Design

In this study, we investigated how engagement with resources that were designed to promote metacognition correlated with student performance through an assignment called the "Synthesis Sheet." The Synthesis Sheet is a worksheet template designed to scaffold the learning process by encouraging students to define key topics, describe and provide relevant formulas and examples, and clarify when specific aspects of the topic are applicable.

Students were provided a list of topics that would appear on the exams. The students then picked a topic to analyze by answering the Synthesis Sheet prompts. These prompts encouraged students to consider different types of knowledge: declarative (facts) [11], procedural (applications) [12], conditional (strategies) [13], and contextual (relevance) [14]. The Synthesis Sheet template provided designated areas where students could write their answers to the prompts. Table 1 describes the type of knowledge targeted in each prompt.

Table 1: List of Synthesis Sheet prompts with the type of knowledge the prompts encourage students to develop

Prompt Number	**Synthesis Sheet Prompt**	**Targeted Knowledge Type**
1.	Select the Main Topic for the Synthesis Sheet	Declarative
2.	Important definitions related to the Main Topic. This may include mathematical formulas.	Declarative
3.	Concept Description: What's the big idea? Can you describe why this concept or topic is true?	Contextual
4.	Related Topics: What other topics in the course are connected to the Main Topic?	Contextual
5.	In what situations is the Main Topic relevant? How will you know when to apply these ideas to solve different types of problems? Note tricky exceptions or edge cases.	Conditional
6.	Examples: How can the relevant concepts or formulas facilitate problem-solving? What types of information can their application yield? Show examples and create schematics to show how to apply these concepts	Procedural
7.	Why is Main Topic important in the context of the class?	Contextual
8.	Muddy Points: What aspects of this topic still confuse you? What questions do you still have?	All knowledge types

To evaluate how the Synthesis Sheet intervention improved students' academic performance, our study posed two research questions:

- RQ 1: To what extent does engagement with the Synthesis Sheets predict student performance in the course?
- RQ 2: What suggestions do students provide on the Synthesis Sheet assignment?

Methods

Our study utilized quantitative methods to relate engagement with resources to academic performance. Additionally, we collected qualitative student feedback. Data sources and analysis are summarized in Table 2.

Table 2: Summary of data sources and methods of analysis

Data	**Data Source**	**Analysis Rationale**
Exam Grades	Canvas Learning Management System	Exam scores serve as a metric of student performance
Student Resource Utilization	Post-exam reflection questions	After each exam, students completed a reflection assignment where they reported their academic resource use. This data was correlated with student exam performance.
Synthesis Sheet	Required pre-exam Synthesis Sheet assignment	Synthesis Sheets were scored to determine how Sheet quality correlated with student exam performance.
Student Feedback on the Synthesis Sheet	Qualitative data provided by students in the post-exam reflection	Student feedback gave insights into how to redesign the Synthesis Sheets for future courses.

Data Analysis

Students were required to complete a minimum of three Synthesis Sheets, one before each exam. The responses to each Synthesis Sheet prompt were graded on a 3-point rubric, where a "1" represents a response with inaccurate or missing information, and a "3" indicates that the student provided a clear, detailed, and accurate answer. The data from the post-exam reflection survey, exam scores, and Synthesis Sheet scores were cleaned, compiled, and analyzed with MATLAB. A reflexive thematic analysis [15] was used to identify core themes from qualitative student feedback. The researchers interpreted the data through educational theories like self-regulation [4] and metacognition [2], along with their personal experience, to uncover meaningful patterns [16].

IV. Results

Perceived Usefulness

Analysis of the final post-exam reflection showed that while students struggling in the course were more likely to find the Synthesis Sheets helpful, students entering the class with clear study strategies did not find the exercise beneficial. After each exam, students were asked "How helpful was the process of creating the synthesis sheet?" with five Likert-type response options:

"Extremely Helpful," "Very Helpful," "Moderately Helpful," "Slightly Helpful," and "Not At All Helpful." When students said that the sheets were "Extremely Helpful" or "Very Helpful," we considered this a positive view of the sheets. We considered "Slightly Helpful" or "Not at all Helpful" responses to be a negative view of the sheets. We analyzed the final post-exam reflection because it represented the strategies students found most beneficial at the end of the course and the resources they used to prepare for the final exam.

We then determined if students who performed well in the class, defined as earning a 77% (C+) or higher for the final course grade, were more likely to find the sheets useful. Notably, students who struggled more in the class found the Synthesis Sheets more helpful, while the majority of students who performed well overall had a negative opinion of the assignment (Figure 1).

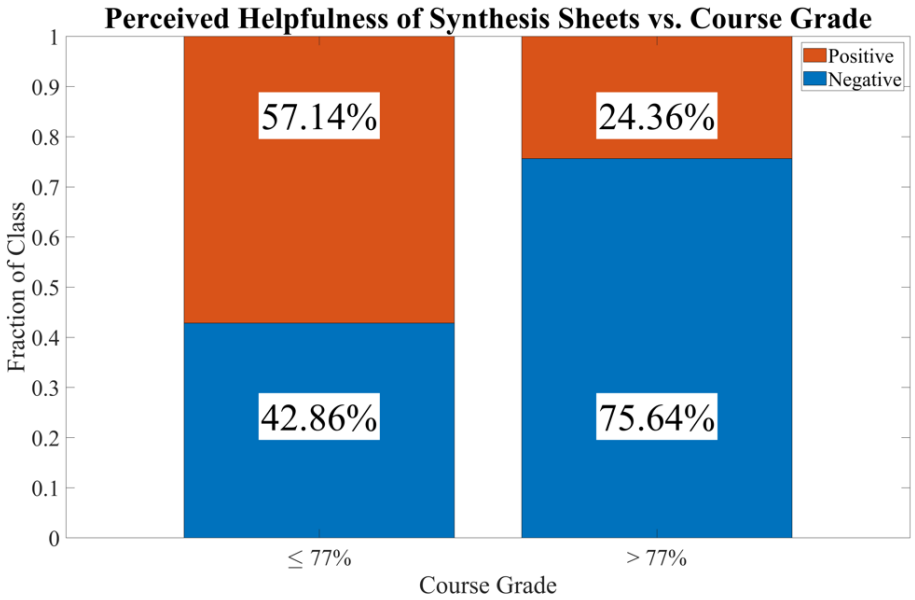

Figure 1: A chi-square test of independence was performed to examine the relation between course performance and positive sentiments on the Synthesis Sheets. The relation between these variables was significant, X^2 (1, N = 256) = 12.21, p = .00048. Students with grades below 77% in the class were more likely to find the Synthesis Sheets helpful.

The qualitative feedback from students supported these quantitative results. Students who enjoyed the Synthesis Sheet assignment noted that the structure of the assignment was helpful and wanted to use the framework of the sheets in other areas of the course:

> *"I used the synthesis sheet for a topic I didn't quite understand, and because I had no idea how to answer any of the questions, it motivated me to study extra hard for the topic, until eventually I was able to confidently answer all the questions in the end. I think it asks all the right questions."*

> *"I think that the synthesis sheets are set up well because they do force you to get into the habit of repeating the definition for certain topics over and over again to reinforce learning. For me personally, I did my synthesis sheet on logical operators, and I definitely felt like that was a topic I felt relatively confident in while taking the midterm."*

However, numerous students noted that the format of the sheet did not align with the study methods they already had in place and did not like that the assignment was required:

> "*I feel like the synthesis sheets force a style of learning that doesn't suit everyone's own way of studying. Personally, I don't find the synthesis sheets helpful because I like to take notes in my own way with my own guiding questions/standards. Because I already took notes that way to study for the exam, having to write the synthesis sheet felt like a way of forcing a different learning style upon me, that ended up confusing me a little."*

These results suggest that Synthesis Sheets were perceived as helpful for students who did not already have a clear study method in place. Students who entered the class with a preferred method of notetaking found the Synthesis Sheets overly restrictive. This highlights the challenge of designing a universal assignment that is viewed as beneficial by all students.

Synthesis Sheet Engagement & Student Performance

Students initially viewed Synthesis Sheets negatively. However, those who adopted Synthesis Sheets as a primary study resource by the mid-point of the course outperformed their peers on the final exam. Post-exam surveys asked students to identify the resources they used to prepare for the exam, such as Class Notes, Drop-in Tutoring, Peer Guided Study Groups, Professor Office Hours, Synthesis Sheets, and TA Office Hours. For this analysis, we focused on resource selection to prepare for Exam 2, as mid-quarter engagement reflected students' informed and intentional resource choices after experiencing Exam 1 (MATLAB programming) and preparing for Exam 2 (Linear Algebra).

Final exam performance was compared to resource use. The average final exam score and standard error of each group were then plotted against the class average (red line in Figure 2). While most resources showed no significant correlation with performance, students using Class Notes and Synthesis Sheets scored approximately half a letter grade higher than their peers. These findings suggest that Synthesis Sheets enhance performance, even if students do not immediately recognize their benefits. Future research will explore other variables that may impact performance, such as the number of Synthesis Sheets prepared and student study habits.

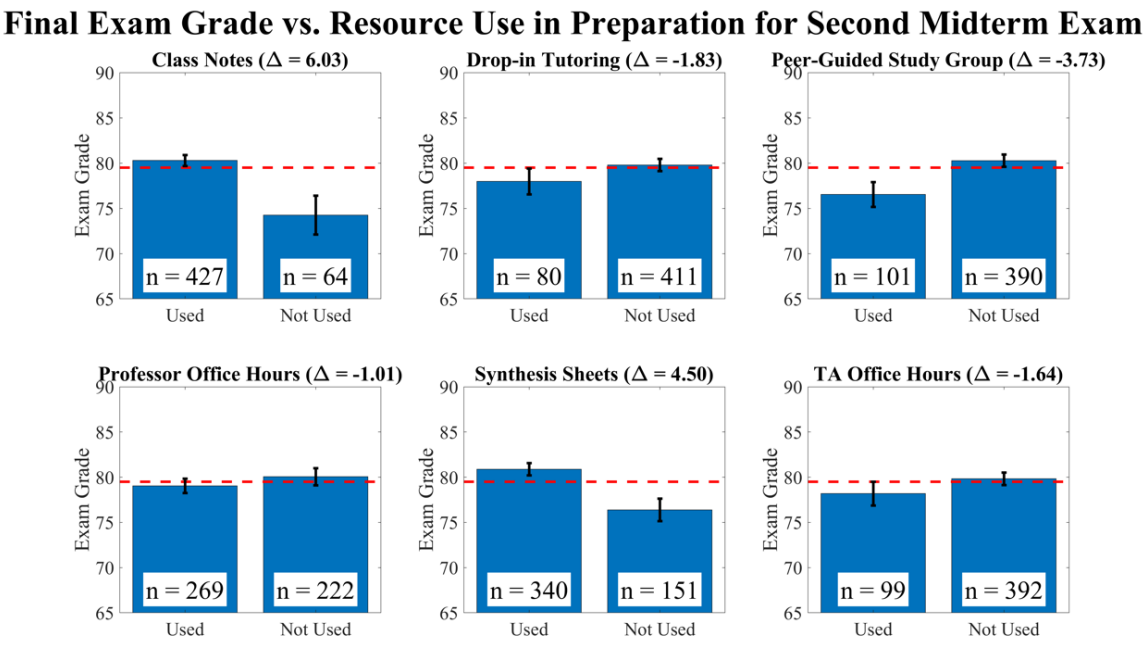

Figure 2: Analysis of reported student resource engagement compared to their final exam scores indicates that using Class Notes and the Synthesis Sheets positively impacted student exam performance. The class average on the exam is plotted in red.

Synthesis Sheet Performance as Predictor of Exam Performance

The Synthesis Sheets encouraged students to synthesize different types of knowledge: declarative, procedural, conditional, and contextual. Each question on the Synthesis Sheets was scored on a 3-point scale, as presented in Section III. Notably, students who performed poorly on the conditional knowledge question (i.e., "Prompt 5: In what situations is the Main Topic relevant? How will you know when to apply these ideas to solve different types of problems? Note: tricky exceptions or edge cases"), had a lower average on the final exam.

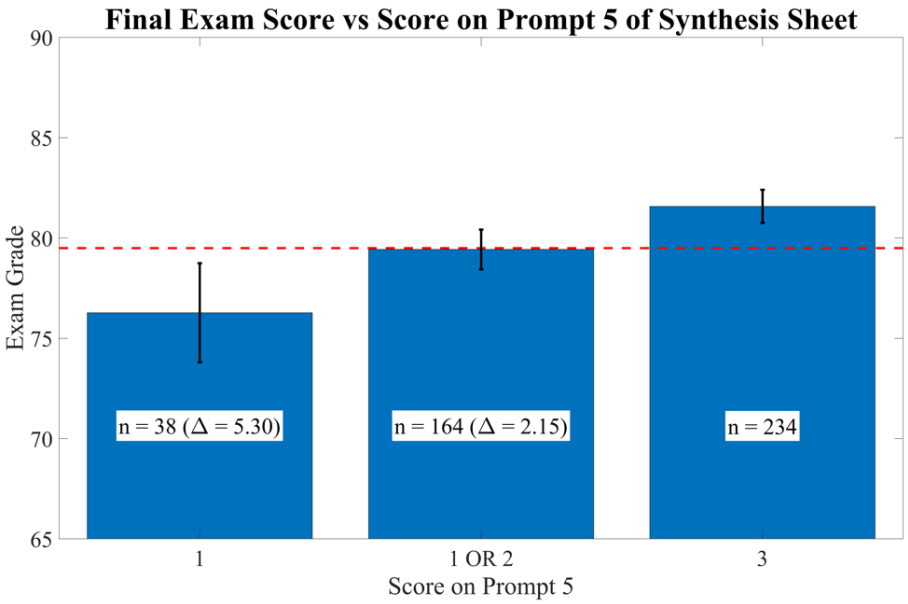

Figure 3: Students who received the lowest score on Synthesis Sheet Prompt 5 (conditional knowledge, scored out of 3 points) received lower scores on the final exam than their peers. Reported Δ values show the difference in the final exam average compared to the performance of students who received a 3 on the conditional knowledge prompt.

While further analysis is necessary to confirm this finding, the results suggest that Synthesis Sheet engagement correlates with improved performance and that specific understanding of conditional knowledge may also correlate with improved performance in the course.

V. Conclusions & Future Directions

For students struggling in the course, the Synthesis Sheets were a helpful tool. Moreover, there is evidence to suggest that Synthesis Sheet use correlates with improved exam performance, differentiating the Synthesis Sheet from other available resources.

While the results are promising, we must still consider who we are designing the tool for. The current sheet works well for students with less developed study skills or methods of organizing information. A key question for future investigation is how we can make this a more useful tool universally to improve buy-in from other members of the class.

Based on student feedback, we have identified and implemented three changes to refine the Synthesis Sheet:

1) Reducing the number of prompts, simplifying their language, and adding example instructions.
2) Encouraging students to answer the prompts using different formats rather than sticking to a strict template. This will help students personalize their Synthesis Sheets.

3) Developing specific language to tailor the Synthesis Sheets to programming topics since students felt that the original prompts did not work well with the coding topics presented on the first exam.

Table 3: Example versions of the revised Synthesis Sheet prompts. Potential prompts to better tailor the Synthesis Sheets for coding topics are noted in **bold**.

Prompt Number	**Revised Synthesis Sheet Questions**	**Targeted Knowledge Type**
Instructions	"Choose a topic to focus on. Your notes on a topic should help you clearly define WHAT a topic is, HOW to use it, WHEN it applies, and WHY it's important. Use these prompts to create a cheat sheet for a topic. The topic you choose can be broad or narrow. Use your preferred method of organizing knowledge (drawings, schematics, worked examples, etc.)."	
1.	Define the main topic of your synthesis sheet. Record any related definitions or mathematical formulas.	Declarative
2.	Show examples of how to use the main topic in problem-solving. Create drawings, schematics, or examples to help you explain this information to a peer. **Comment on an example piece of code to explain the function of the topic to a peer. Feel free to use class examples.** **Write your own code that shows the main topic in use.**	Procedural
3.	How will you know <u>when</u> to apply the main topic to solve different types of problems? Are there other similar concepts in the class and how do they differ? **How will you know <u>when</u> to use this coding method? What types of problems or scenarios can be solved using this coding method?**	Conditional
4.	Why is this topic important in the broader context of the class?	Contextual

Rather than providing a designated space for students to write their responses to each question, the Revised Synthesis Sheet will encourage students to organize their knowledge as they see fit.

Future Directions

The results of this Work-in-Progress are promising. Future studies will launch the refined Synthesis Sheet Prompts, adjust post-exam reflections to gather more data on resource use, and further analyze links between conditional thinking and performance. We encourage instructors to adopt the Synthesis Sheet framework and identify which knowledge type—declarative, procedural, conditional, or contextual—is most challenging for their students.

VI. References

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