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Cognitive Domain of Learning: Exploring Undergraduate Engineering Students' Understanding and Perceptions

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Abstract

This paper is a research paper. Learning is an integral part of our lives. Each one of us learns the same things differently based on our preferred way of learning. We can learn by building mental models; through feelings, emotions, attitudes; and by physical movements. The different ways we learn, or the domains of learning, are broadly categorized as cognitive (knowledge), affective (attitudes), and psychomotor (skills). This research study will focus on the cognitive domain alone. The cognitive domain focuses predominantly on learning using mental models which requires individuals to think and create new and/or build on existing models. This domain has been categorized into a hierarchy of skills or levels based on the learning processes. The six hierarchies of the cognitive domain are knowledge, comprehension, application, analysis, synthesis, and evaluation. This research study aims at answering the following research question, 'How do undergraduate engineering students understand and perceive learning through the cognitive domain of learning?'.

A qualitative research design approach was used, and the interview questions were designed based on the six hierarchy levels of cognitive domain. Five participants from varying academic levels were recruited from different engineering disciplines to participate in an online interview (Zoom) of 45-60 minutes. The interviews were audio recorded and transcribed so it could be coded for further analysis. Three of the five participants mentioned that the process of taking notes and creating mental models takes time and that these processes used to be, or still are difficult. When asked about creating mental models related to the knowledge hierarchical level, all participants stated that they would not create mental models for facts or definitions of a concept but would attempt to memorize it. To further develop a mental model using the *understanding* hierarchical level, all participants needed to conduct further research to learn about a new concept, predominately in the form of looking up additional examples of how to solve or think about a new concept. In creating a mental model through the *application* hierarchical level, participants would assess similarities and differences between concepts, test ideas, and conduct further research as needed. Within the *analysis* hierarchical level, participants would use mental models by breaking down information into (1) what was given or what was known (2) additional information was needed and (3) steps needed to solve the problem. If participants used the *synthesis* hierarchical level to build a mental model, information would be connected to old mental models to create a larger mental model or wider understanding of a topic. Finally, when asked about use of mental models within the *evaluation* hierarchical level, four participants had a clear way of determining a concept's importance.

Keywords: cognitive domain, mental models, undergraduate engineering

Introduction

Learning is an integral part of our lives. Each one of us learns the same things differently based on our preferred way of learning. We can learn by building mental models; through feelings, emotions, attitudes; and by physical movements. Based on this, the domains of learning are broadly categorized as cognitive (knowledge), affective (attitudes), and psychomotor (skills) [1]. Each domain of learning focuses on one of three ways the brain can be engaged in learning. The cognitive domain is focused on mental processes or thinking, the affective domain focuses on feelings, attitudes, and behaviors, and the psychomotor domain focuses on learning related to motor skills and physically doing or relating a concept/topic to real world practices [1]. However, this paper focuses only on the cognitive domain of learning. Researchers interested in learning more about our research on affective and psychomotor domain are directed to the studies [2] and [3].

Cognitive Domain: The cognitive domain focuses on mental processes or thinking, and it can be broken down into six levels of complexity [1]. These six levels, in order of their hierarchy, are knowledge, comprehension, application, analysis, synthesis, and evaluation [1]. Table 1 below provides a description for each of the cognitive domain hierarchy levels.

Table 1 – Cognitive Domain Hierarchy Levels

Level #	Level Name	Level Description
1	Knowledge	Focuses on an individual's ability to recall basic facts and definitions without fully comprehending the facts meanings in a wider context
2	Comprehension	Focuses on an individual’s ability to understand and interpret the knowledge on a deeper level
3	Application	Focuses on an individual’s ability to use their learned knowledge in a new and complex circumstance
4	Analysis	Focuses on an individual’s ability to analyze and break down a problem or concept into its various components
5	Synthesis	Focuses on an individual’s ability to arrange pieces of information -- from the analysis level -- into a constructive form
6	Evaluation	Focuses on an individual’s ability to evaluate a concept or problem in the necessary context

The cognitive domain of learning is predominately taught in a classroom setting through lectures, required readings, and other videos or assignments given to students to learn new concepts and practice their application. This is often the easiest domain to study and test and is therefore the most studied domain [4-7]. The effectiveness of student learning taught with a focus on the cognitive domain of learning is most often evaluated with some quiz or exam [4], [7-8]. This study aims to find general trends in students' opinions on the importance of mental processes and/or which forms of mental processes may be more beneficial or more commonly used by engineering undergraduate students.

Literature Review

There is less extensive research in undergraduate engineering pedagogy specifically, but in the review of literature related to the cognitive domain of learning and teaching at the undergraduate level of engineering, a few applicable studies were found [4-5], [9-11]. These studies were directly testing the effectiveness of different teaching styles or practices on students cognitive learning. For example, one study tested whether pre-instructional learning and self-paced e-learning helped students prepare for and master a topic [4]. This was found to better prepare students for lectures on new concepts, as well as give instructors more time to teach the new concept in class as they did not need to review prerequisite knowledge with students [4]. Similarly, another study found that having more tutorials or example problems was helpful in engineering students' comprehension of math [12]. Other studies tested new e-learning practices and programs [5], [9-10]. They found that this style of learning was the best alternative during the COVID-19 pandemic; however, it also produced more confusion during certain laboratory activities [5], [10]. Recognize that these studies were conducted before and during the pandemic, so newer studies may find different results as online learning and laboratories are improved upon. Another study tested how computer simulations and animations can aid instructors and students learning [9]. It also showed how additional online examples can aid students with higher cognitive understanding and subsequent problem solving [9].

There are many related articles that focus on at least one of the domains of learning for engineering students; however, most have different focuses or are not directly applicable to this paper's research. For example, many related studies were testing or creating a tool used to evaluate a class's ability to teach with one or more of the domains, versus testing how to better teach one or all of the domains or discover how students learn with each domain [6-7], [13-16]. One study created a teaching template for schools so they are more aware of what engineering students should learn during their capstone research [15]. Another study tested the program EvalTOOLs 6 to determine how well a class performed in connecting to each of the three domains and how it may be helpful for determining which domains need more development [13]. A related study tried to evaluate each hierarchical level with an analysis of students' grades [6]. Other studies attempted to develop new analytic tools to evaluate students learning with the cognitive domain [7], [14].

Another related study focused on testing a few hierarchical levels instead of reviewing learning through all of the hierarchical levels of the cognitive domain [8]. One article partially focused on testing or proving that all three domains are connected in the overall learning process -- they are connected [17]. It found all the domains to be correlated when evaluating students' learning, meaning more research should be conducted on how to better connect all three domains in a class structure for deeper understanding, the rest of their findings predominately relate to the affective and psychomotor domain [17]. This idea is directly echoed in another report finding that all three domains need to be intentionally integrated into a class for more effective learning [10]. This idea that the domains are connected is reflected in the fact that many studies focus on two domains at a time instead of only one domain at a time [4-5], [10-11], [17-22].

Several studies exist that research the domains, but they focus on testing a specific class within engineering or non-engineering majors [4-6], [10-11], [17-18], [20], [23]. Similarly, the studies that focus on math or chemistry classes may not have tested solely engineering students, which could still distort or skew results towards conclusions that may not apply to engineering students overall [4], [10], [24]. The problem with these studies is that their findings cannot be generalized for all engineering classes, but their experiment methods could be adapted and reconducted to learn about general engineering learning. It may also be true for studies that focus on specific engineering sub-disciplines [6], [12], [17-18], [20-21], [25-27]. Thus, while there are many studies conducted on the three domains of learning at a collegiate level, there is still much room for further generalizable research on undergraduate engineering courses and teaching practices.

Two systematic reviews or meta-analysis of studies were found [19], [23]. One article reviewed 55 publications and found that the literature was in favor of a flipped classroom style of learning for cognitive learning [19]. However, it also found that "Although the Engineering community has been vocal advocates of the flipped classroom model..., our study found Engineering was the only subject area that had an overall negative effect size albeit non-significant" [19]. They further explain that only five of the fifty-five studies were based on engineering subjects and that many of the studies lacked "mean scores, standard deviations, and number of observations required for a meta-analysis" [19]. This – along with other information missing from a number of the 55 reports – means that these findings may not be representative of the outcome of implementing a flipped classroom [19]. Additionally, their 55 studies were focused on articles from 2013-2016 [19]. Thus, with online learning being more commonly used and the problems with conducting a meta-analysis of this type, newer research should be conducted on this topic, keeping in mind these literature reviews recommendations for future tests [19], [23].

The other systematic review analyzed 32 articles and found that few articles had used qualitative research methods [23]. With this as a background, our research study focuses on qualitatively investigating engineering students understanding and perceptions on their learning through the cognitive domain of learning, as well as provide further evidence to the existing body of research on this topic. This review also found a weakness in articles' readiness to compare students' achievements where approaches were compared but assessments' compositions had changed "leading to unequal correlations" [23]. This unequal correlation shows there are improvements to be made and more research conducted to study students' domains of learning.

Methods

This research aims at investigating students' responses about their cognitive connections towards learning engineering concepts. To achieve this objective the following research question was examined, 'How do undergraduate engineering students understand and perceive learning through the cognitive domain of learning?' A qualitative research design approach was used, and the interview questions were designed based on the six hierarchy levels of cognitive domain (knowledge, comprehension, application, analysis, synthesis, and evaluation).

Procedure

The different steps used in this study include IRB approval, pilot interview, participants recruitment, and conducting interviews are described in this section. First, the study and the interview protocol were approved by the Institution Review Board (IRB). The pilot interview was conducted with an undergraduate engineering student randomly selected from the population to assess the effectiveness of the questions. Following this interview, minor changes were made to the interview protocol and the interview questions were then finalized. Third, the participants were recruited from a large public research university in the United States.

The initial screening survey was sent to several undergraduate engineering students. A total of 90 students responded to the screening survey. Even though 90 students responded to the screening survey, most of them were not available for an online interview. Following students' responses to the survey, five participants with the widest range of demographics were selected, making sure that each was from different engineering disciplines (Please refer Table 2 for more information on participants demographics). We were intentional in selecting participants who were either sophomore or in other higher-class standings to ensure they have relatively more learning experiences to share. The selected participants also represent diverse race/ethnicity and gender identity backgrounds.

Finally, these five participants were invited to participate in an online interview conducted using Zoom. The choice of conducting interviews online was made to ensure all students who received the screening survey could participate without concerns of transportation and increased flexibility as the interviews were conducted during summer 2023. Additionally, conducting the interviews online did not change any of the interview procedures in comparison to if we had held interviews in person: all interviewees were asked the same questions, each interview was audio recorded for further transcription and review purposes. Also, all interviews were blinded (only audio and no video), to avoid biases based on visual appearance. All interviews conducted ranged between 45 to 60 minutes. The interviews were recorded and later transcribed. More details on the data analysis will be provided next.

Table 2 – Participants' Demographics Information

Participant	**Class Standing**	**Engineering Discipline**	**Race/Ethnicity**	**Gender Identity**
P1	6th Year Senior	Mechanical Engineering	Asian	Trans Male/Trans Man
P2	Junior	Computer Engineering	Hispanic or Latin X	Female
P3	Sophomore	Aeronautical Engineering	White	Female
P4	Sophomore	Biomedical Engineering	Asian	Male
P5	Senior	Industrial & Systems Engineering	Black/African American & Hispanic or Latin X	Male

Data Analysis

Each interview recording was transcribed using Zoom's transcription function, and then the transcriptions were (re)read with the recording and small errors in the transcription were fixed. Additionally, time stamps were added to the interview transcripts for later review as needed. After transcription, NVivo was used to code and organize the data for further analysis. The interviews were coded in relationship to each interview question asked [28-29].

Results, Analysis, and Implications

In the interviews conducted, the cognitive domain was often connected to the participants' use of – or thoughts on – mental models, which were described as diagrams, drawings, note taking, or some other visual representation which assisted a student in learning new concepts and internalizing that information within a mental model. The following section examines each interview question individually. Each question starts with how the question directly connects to a hierarchical level. Then, they present the participants' responses, analyze those responses to understand participants' perception, and further discuss the implications of the responses and resulting trends.

Participants were asked two introductory open-ended questions (Q1-Q2) related to their perceptions about learning. Next, participants were asked three questions (Q3-Q5) about their use of the cognitive domain in learning different or new concepts. Then, participants were asked six questions (Q6-Q11) directly related to the six hierarchical levels of the cognitive domain (see Table 1 for details on hierarchical levels). Finally, participants were asked (Q12) which of the three domains they preferred to learn with and why. It should be noted that this interview consisted of questions about all three domains, and the results were split into three papers to better emphasize the findings related to each domain of learning. In this paper, we focus only on the cognitive domain of learning. Readers interested in understanding more about the research on affective and psychomotor domain are directed to the other papers from this project [2], [3].

Q1: How do you perceive learning as a process?

Learning is an integral part of our lives. Each one of us learns the same things differently based on our preferred way of learning. In this question, students share their perceptions on learning as a process.

Overall, participants P1 and P3-P5 noted that examples, practice, and repetition were remarkably important in the learning process.

> P4: *You have to continuously either learn it in class, and then keep practicing those same concepts. You just have to keep practicing it if you want to learn.*

Please note that the other participant (P2) did not say they were against this belief; instead, they noted that learning is a never-ending process.

> P2: *I don't think learning is really something that ever ends because there's limits to the things that we can do. We kind of approach the limit of perfection asymptotically, like we can get super close, but we can never quite reach it.*

Participant P2 noted that practice and example problems are important in some of their later responses. P1 also noted their belief that learning is non-linear, individualized, and may come from being taught or from self-teaching oneself a concept. P3 emphasized the need for one to understand why things happen the way they do when learning new concepts. P5 also expressed a fondness for learning and finding example problems on YouTube as they often must teach themselves different concepts. P5 specifically credits this need to professors' desire to challenge students by not giving many examples and/or not explaining concepts in enough detail. P4 also stated that watching YouTube helped them better understand a concept better but noted that YouTube is not the only thing students should use to learn, as practice and repetition is also important.

> P5: *I understand professors want to challenge kids and see what they can do, but I feel a bit lost when it comes to learning new material. Honestly, YouTube was my best friend, especially for specific examples or general theory.*

> *P4: I feel like you have to go through the steps. Like you can watch a 15-minute YouTube video but you can't stop there. You have to like continuously learn it in class and then keep practicing those same concepts either the night after or the day before class or whatever you just have to keep practicing it if you wanna learn.*

Based on the participants' responses, it is observed that the participants explicitly talk about practice, repetition, and having many examples when learning a new concept. The participants also expressed that they find having additional practice, repetition, and examples beneficial. Three of the five participants specifically noted their willingness to conduct further research outside of class for a better understanding of concepts and/or to find additional examples. Thus, instructors and researchers might explore the specific types of examples and practice problems that aim at enhancing students' learning experiences through the application of the cognitive domain of learning. Additionally, they should also examine the number of problems given to students to solve versus the number of problems for students to practice.

The engineering students' responses also show that they desire additional information, examples, and explanation of engineering concepts for the development of their mental models. Also, their responses indicate that participants understand that learning new concepts takes time and have complex connections to a variety of application problems. Additionally, keep in mind that as P1 mentioned, some learning can be individual, and some learning is better suited for a traditional classroom learning style. Thus, research on the usage of different learning modalities (online, in person, or asynchronous) in engineering with a focus on the cognitive domain of learning might be beneficial to teaching engineering topics more efficiently. A few studies on engineering education with online components testing learning within the cognitive domain were found in research for this report [4], [8]. Another study reached a similar conclusion of hoping to further test and research e-learning approaches [12]

Q2: What, in your opinion, are some different ways or approaches that you can learn by?

Overall, all five participants noted that taking notes, seeing problems worked out, and trying them on their own were important approaches to learn from. Three of the five participants (P1, P3, and P4) also mentioned some form of hands-on learning being important. An excerpt from participant 1 is below.

> P1: *I think things like note taking and repetition work for a lot of things, but I also think hands on learning and applications are very important to understanding a lot of concepts.*

Participant 2 (P2) made a light connection to the affective domain by expressing frustration with graded homework noting that it adds pressure to get the right answer. They further stated that they would be "excited" to do homework if it was participation based instead of solely accuracy based.

> P2: *Something that always makes me really struggle with homework problems is the fact that it's a lot of pressure to try to have to get everything a hundred percent right the first time. I've found it the most helpful whenever my professors will assign homework problems that are purely for participation. I feel like it made me excited to do the homework because I wasn't dreading it and staying up all night stressing about it.*

Participants P4 and P5 also distinguished auditory learning versus straight visual learning with examples and slideshows. P1 also specifically mentioned being able to ask questions about a concept to deepen their understanding. Finally, P4 and P5 noted trying to understand each part of the whole equation and/or process. An excerpt from P4 is below.

> P4: *For me, I'm more of a visual learner than auditory, so I like to see the steps and how they're done step by step. I just have to see it. Even for like chemistry, like a reaction mechanism with the arrows and where the electrons are moving.*

All five participants value the cognitive domain of learning and three out of the five participants (P1, P3, and P4) explicitly connected to the psychomotor domain of learning. On the other hand, only P2 made a connection to the affective domain, though it was a tangential connection to how P2 would be more excited to do homework with less pressure of getting a decent grade. Thus, this shows how participants are most familiar with the cognitive domain, less aware of the psychomotor domain, and least aware of the affective domain. Although participants are most familiar with the cognitive domain, there is still much to be researched. For example, as P4 and P5 mentioned visual and auditory learning, research may determine which type of learning may engage the cognitive domain more effectively and help students create mental models easier.

Q3: As a part of learning a concept or topic, how often do you create mental models or processes?

This question was one of the main questions in the interview as it helps us understand students' perceptions of their understanding on creating mental models and processes as a part of their learning process. Overall, all five participants say they typically create mental models when learning.

> P5: *I create flow charts all the time because it helps me organize my thoughts and keeps me organized.*

Participants P1 and P3-5 mentioned taking notes, drawing diagrams, making flow charts, and breaking down complex ideas. An excerpt from participant 3 (P3) is provided below.

> P3: *Oftentimes, I will use models such as drawings or printing off pictures or diagrams. I need something that can help break down concepts and explain each individual part, like in science having parts of a cell.*

Participant 2 (P2) on the other hand said they rarely take physical notes; instead, they typically listen to lectures and practice problems developing mental models in their head. P2 also noted their reliance on relating new concepts to previously learned concepts when creating mental models.

> P2: *I create constructs in my head, and I try to relate all of the concepts to things that I've learned earlier to build a map of how the concepts relate. But honestly, I don't really take notes in my classes. I just show up and I'll do the problems with the professors, but I don't really take notes.*

In summary, the analysis of the student responses shows that all participants create mental models when learning new concepts. However, most of the participants feel the need to physically develop their mental models with traditional forms of note taking versus P2 who solely creates mental models in their mind, without writing things down. Further quantitative research will be required to determine if P2 is an outlier among most engineering students, or if there is a sizable portion of engineering students that do not rely on taking physical notes. If there is a sizable portion of engineering students that do not take notes, it may be interesting to see how common it is for some disciplines within engineering to not take notes over others, and how it might affect the teaching of those disciplines' specific courses. For example, P2 said they do not take notes and they are studying to become a computer engineer. Thus, if quantitative research showed that computer engineers are less likely to take physical notes, then classes for computer engineers may be taught in a different way, such as de-emphasizing taking notes and emphasizing projects to begin with.

Additionally, a later question shows that some participants currently struggle or have struggled with taking notes in the past. Thus, since participants believe note taking to be important but is or has been difficult, explicitly educating students on the most helpful forms of note taking might be important and useful in their learning process. Similarly, it might be beneficial for students to be taught a variety of ways to take notes, so students can discover their preferred way of taking notes.

Q4: How do you feel about creating mental models/processes? Does that come easy to you, or do you spend more time thinking about it?

Creating mental models to learn concepts is a preferred approach for four out of five participants in this study. Hence, it is important to understand their perceptions and ease of coming up with mental models when learning a concept/topic. The participants P1 and P3-P5 all acknowledged that at times, it has been difficult taking notes. Currently, P1 and P5 have less trouble with taking notes and creating mental models.

> P1: *It was definitely a learned skill. It's something that I don't find difficult now, but it was difficult earlier in college because I was only taught one specific way to take notes in high school that didn't really work well for me. And, when I got to college, I wasn't used to taking notes because I never really had to before, so I had to figure it out for myself.*

> P5: *I have to spend some time thinking about it, but once I figure out how I want to format my mental model it picks up from there.*

On the other hand, P3 and P4 both agree that creating mental models is difficult and takes some time to develop. However, P3 emphasized mental models' importance especially during tests as it is easier to mentally picture their notes. P4 also noted that organizing all the information adds to how long it can take them to develop their physical notes. In contrast, P2 rarely struggles to create mental models.

> P2: *I feel like it's always come pretty easy for me. It kind of goes with not taking notes, but I can just very easily relate concepts to other things.*

These responses continue to show the importance of creating mental models. The biggest difference is that P2 does not create physical models to better understand new concepts. This again points towards a need for further investigation into whether it is common for a portion of engineering students to not take physical notes. If further research finds that some students do not benefit from taking notes, it will further emphasize students' reliance on a multitude of examples and practice problems as a way of understanding new engineering concepts. Also, if further investigation finds that computer engineers, such as P2, do not benefit as much as other engineering sub-disciplines from taking notes, it would be interesting to explore the most used cognitive practices by students in computer science majors. This is in comparison to the other four participants – who rely on taking physical notes.

Another interesting trend found was how participants' response (other than P2) related to their class standing. Participants P3 and P4 are sophomores who agreed that taking notes can be difficult and takes a lot of time. On the other hand, P1 and P5 are seniors that agree taking notes is easier now or becomes quicker after spending a bit of time deciding how to format one's notes. This is reasonable as P1 mentioned taking notes being a learned skill, thus students who have taken more classes should in theory find it easier to take notes than a freshman or sophomore. P1 also made an interesting comment on how their high school note taking was not helpful once they started college. With this knowledge, it may be beneficial for engineering students to be taught a variety of ways of taking notes in introductory engineering classes. This way students will be able to find and develop individualized ways of taking notes as they begin taking classes that require note taking and developing mental models.

Q5: How important is creating mental models in the process of learning?

Overall, all participants believe creating mental models to be important in the process of learning. However, P3 did note that it is most helpful for understanding complex systems and clarifying new topics or systems.

> P3: *I think it depends. Like I think if it's in English, then it's not going to be super helpful. But if there's a complex system, I think it helps me be able to identify what the system looks like and introduce you to a new topic at least. And once you understand that, then you can master the topic.*

On the other hand, P2 continued to emphasize the importance of making connections within a singular mental model or from one mental model to another.

> P2: *I think it's extremely important. I feel like it's a very big thing for me to be able to relate it across different concepts or classes. If I didn't make such an effort to try and think about these things like that, then I wouldn't really have an understanding of the concept. I would just be regurgitating basic facts.*

Participants P1 and P3- P4 also made connections between having physical notes and studying or reviewing for tests when explaining the importance of creating mental models.

> P4: *Without them, I don't think I would be able to learn at all. Not only does it help me learn, but it helps me like review for a final exam since I can quickly look back on my notes.*

Although mental models can take time to develop, all five participants believe they are important. However, most participants made a connection between mental model's importance to the class they are enrolled in or grades. Participants P1 and P3-P4 connected their physical mental models to an ease of studying and/or reviewing for a test. This shows that participants have many reasons for why they believe mental models are important. Participants have found that mental models are not only helpful in organizing facts, their thoughts, and identifying connections to other concepts, but they are also helpful for reviewing the concepts later. Also, participants spending more time developing these mental models before a test shows their willingness to delay gratification to learn and do well academically. Further research should be conducted to show if this willingness to delay gratification is common for engineering students. If it is not, it may be beneficial to research how to structure classes to help students develop a willingness to delay gratification in a similar manner and understand concepts in more depth.

Q6: ***When remembering facts or the definition of a concept or topic, do you create a quick mental model or process in your mind?***

This question directly relates to the first hierarchical level of cognitive domain *knowledge,* which focuses on an individual's ability to recall basic facts and definitions without fully comprehending the facts' meanings in a wider context [1].

Overall, all participants indicated they do not create a mental model for a specific definition; instead, they often add definitions and quick facts to a mental model of a wider concept.

> P3: *I don't know that I would use a mental model for terms and definitions. If there's multiple things that one thing is or can do or is connected to, that's usually when I would create a mental model since there's multiple pieces and parts. But, if it's just like term and definition, I probably wouldn't use a mental model.*

Each participant does this in their own individualized way. P1 has no strategy for remembering quick facts and definitions.

> P1: *I don't do anything intentionally in my brain. It's kind of either you remember it or you don't for me.*

The participants P2 and P3 mentally connect these facts and definitions to other more concrete concepts. An excerpt from participant P2 is below.

> P2: *I found relating the abstract concept to a more concrete things helps me better understand a concept.*

When initially learning a new concept, participant P4 color codes their notes so facts, definitions, and other pieces of information are easy to find and quickly referenced before these concepts are memorized. This helps them memorize and further develop their mental models when practicing and reviewing information about a concept. When developing their mental model, P5 relies specifically on writing the facts and definitions down repeatedly.

This information shows that most engineering students find quick facts and definitions important to learning; however, they interpret facts and definitions as being a component of a mental model versus something that is the center of a mental model. However, all participants continue to see the importance of mental models in learning and connecting a variety of ideas to one another with mental models. In relation to the hierarchical level *knowledge*, it seems participants have little to no problem understanding quick facts and definitions. Further investigation would be required to determine if this is common for engineering students compared to other degree paths. Additionally, it is important to investigate the best way for engineering students to learn and memorize quick facts and definitions, and its influence on learning complex concepts in the future.

Q7: How do you approach a concept/topic that you already know, and how do you try to understand that concept/topic? Or how/what type of mental model do you normally create? Is there a type of mental model that you use more often than another or does it depend on the class/type of class.

This question relates to the second hierarchical level of cognitive domain *comprehension* which focuses on an individual's ability to understand and interpret knowledge on a deeper level [1].

All participants agreed they would review old notes or focus solely on the parts of the concept they did not understand when they previously learned a particular concept/topic. However, what they would do from there varies. Participant P1 said they would ask questions to someone more knowledgeable or conduct further research if they did not know of someone more knowledgeable.

> P1: *If I'm revisiting a topic and don't have outside input or output, I would re-read books, do a lot of internet searches, maybe watch some YouTube videos, listen to podcasts, etc. It really just depends on the subject.*

Participants P2 and P3 said they would try to re-create their mental model by adding to it, relating it to similar concepts, and focus on deepening their understanding of the concept. P4 and P5 said they would attempt a mix of reviewing old mental models or notes, reviewing the process to solve problems, and re-working the problems.

> P4: *I would look back on my old mental models and go back to the practice problems. I would try problems without looking at my old notes, then look back at my notes for old examples and to try to answer my questions. It's like a little cheat sheet from my old notes when re-viewing and trying old problems.*

Participant P5 also noted they would take care to note anything important from the perspective of this new professor but would avoid taking notes on the part of the concept they already understood. Additionally, P1 and P3-P4 said their mental model format depends on the class.

> P1: *I take notes differently for every single class. I think it's very subject dependent for me. I'm not going to have pictures in a math class unless I really need them. I'm more likely to have images for like a science class where I need to document the physical set up.*

However, P2 does not take physical notes but instead tries to remember important words, definitions, and connections. Finally, P5 said they generally use flow diagrams or hierarchy bullet notes.

> P2: *I might try to think of an acronym maybe, but for the most part I'll try and remember important words or definitions. And I try to remember the other concepts as like natural extensions of the concept I'm learning.*

> P5: *I frequently use flow diagrams and create a hierarchy within them, and that works pretty well. But other than that, I just take random notes that I think is important*

When it comes to re-learning a topic, participants widely said they try to review old notes or mental models and ask questions or conduct research to deepen their knowledge of the topic. Thus, when it comes to comprehension of a concept participants already know, participants highly value old notes and practice problems, as well as asking questions and further researching the topic to gain a deeper understanding of said topic as needed. Also, to better understand new concepts, participants stated they have different forms of mental models depending on what type of class they are taking. Again, further investigation would be required to determine what forms of note taking are more appreciated within the engineering field. However, if those are determined, it may be helpful teach those forms of note taking to upcoming engineers so that students can determine which style works best for each individual's learning. This is emphasized by the fact that three of the five participants said they use different styles of note taking depending on the class, and all five participants mentioned taking notes and trying practice problems as a primary form of cognitive learning in Q2. To reiterate, if students were taught how to take notes, learning engineering concepts may be easier and lead to more students successfully completing the course and thereby increasing the graduation rates.

Q8: How do you use your existing knowledge when applying it in a new situation? What is the process/mental model you follow?

This question relates to the third hierarchical level of the cognitive domain *application*, which focuses on an individual's ability to use their learned knowledge in a new and complex circumstance [1].

Essentially all five participants said they just take their knowledge about the subject or related subjects and try to apply it to the current problem.

> P2: *If I'm taught a new concept in like a math or physics course I'll try and see what I could do with the previous concepts to try and get to that conclusion. For example, I will try and see how I could get from a circle in 2D space to a sphere in 3D space with my previous knowledge.*

Participants P4 and P5 also noted that they would review old notes about related topics before trying the problem. Participant P3 noted that they would try and follow the scientific process. An excerpt from participant P3 is below.

> P3: *I would follow the scientific process and test to see if something is true or if it was just a coincidence. Then, do some more research as research is always the answer. If it doesn't follow the rules, I would essentially go back and try something else or do more research.*

From the participants' responses, there is no clear or singular process that participants commonly follow in creating mental models when applying their existing knowledge in a new situation or a circumstance. Instead, most participants just attempt to apply mental models they have created to a new concept with minimal intentionality as to how they attempt this. Participants mostly cited a readiness to attempt a problem and trial and error their way through a new problem. Participants P4 and P5 noted reviewing old notes in case their old notes had any pertinent information their mental models lacked, or they had forgotten over time. Then, P3 mentioned following the scientific process and conducting additional research for more information as necessary. This shows that the hierarchical level of *application* is not as much of a process with multiple complex steps; instead, it seems to be more of a learned skill where readiness to try and fail is necessary. These responses also emphasize the importance of clear and organized notes, research, and many examples as it helps refresh and develop their mental models in relationship to new situations. This strengthens the need for additional research on how to better prepare engineering students with the skill of taking notes, research, and having professors give many examples and practice problems for students.

Q9: What is the process or mental model you use when analyzing a problem or concept? What role do mental models play in this process?

This question relates to the fourth hierarchical level of cognitive domain *analysis*, which focuses on an individual's ability to analyze and break down a problem or concept into its various components [1].

Overall, all participants have their own way of breaking down a problem that typically revolves around determining what parts of the problem one is or is not familiar with. Participant P5 mentioned analyzing the key words and phrases in a question and any given diagram or finding a helpful diagram as needed.

> P5: *I will analyze the important parts of a question, look for key words/phrases, look at the given diagram or find a helpful one and work on it from there.*

> P5: *I would say analyzing important parts of a question or what they're wanting me to know, and then I have important key words or key phrases. Then, I can use this diagram if its given or find another helpful diagram.*

Participant P1 compares the current problem or situation to the final desired goal, and then tries to determine the intermediate steps to solve the problem. An excerpt from participant P1 is below.

> P1: *I guess for analytical engineering problems, it's always good to look at the current state of something or the current set up of something and the desired goal. Then, fill in the intermediate steps as much as possible. In theory, you should have an understanding of, okay, now that I know what X, Y, and Z are I can do certain steps to get there. If you can't, then you've hit a block, and you know that there's something you're missing and can go learn independently or ask people with expertise on the matter to fill those gaps.*

Similarly, P2 talked about how concepts relate to each other to determine what needs to happen to solve the problem. Additionally, P4 mentioned finding those with additional knowledge and/or conducting further research or finding similar problems on YouTube. P4 also talked about reviewing old mental models and notes for clarity on how to solve the problem and/or its intermediate steps.

> P4: *If I don't know something, I'll usually go to YouTube and I'll try to figure it out. If anyone else can show me what their way of thinking is, then I usually just apply their steps or how they did it. Or I'll look at my own notes or mental models.*

All participants have their own way of breaking down a problem in a way that makes sense to them. Additionally, all participants talked about their method of breaking down a problem in a rather matter of fact way. This indicates that participants generally have minimal trouble breaking down a problem. If participants do get stuck or have a problem, they typically have ways of solving these problems: they commonly review old notes or mental models, conduct further research, or find others with additional knowledge. It should also be noted that all these participants, who are sophomores to seniors, all had their own method of analysis. Thus, further investigation would be helpful to determine whether it is true that most students within engineering are very capable of breaking down problems. In this study, we found that our five participants do not find analysis difficult. Exploring this finding further to understand how engineering students in general approach a problem and how they utilize mental models in the process could lead to an interesting finding. These findings may inform approaches that help students with the skill of breaking down and solving problems with the help of mental models. It would also be helpful to determine if engineering students' class standing has an influence on how students perceive breaking a complex problem and solve it using mental models.

Q10: What is the process you use to synthesize or integrate information or knowledge related to different concepts so that a new meaning or new mental model is established?

This question relates to the fifth hierarchical level of the cognitive domain *synthesis*, which focuses on an individual's ability to arrange pieces of information – from the *analysis* level – into a constructive form [1].

Responses to this question have similarities to the previous questions responses. Participants P1-P2 and P4 continued to talk about finding similarities and relating parts of a topic to old mental models or notes. Participant P1 made sure to mention that they will review old notes to make sure the information is applicable, but then they will combine the pertinent information into a new mental model. P4 does something similar, but they specifically mentioned copying and pasting parts of their old notes on the iPad program Good Notes. P3 continued to reference searching the internet and talking to others to find different perspectives or ways of solving a problem.

> P3: *I probably shouldn't use the internet as much as I do, but I try to see if I can find models or examples of what I am learning online because sometimes it's hard to create a way to learn that thing on my own. It's very helpful to have other people, or even previous professors, and use what other people have made or done to help me learn that topic.*

Similarly, P2 used the example of finding different proofs for the Pythagorean theorem to decide which method is most intuitive for themselves and to see different perspectives on how to solve problems.

> P2: *For example, I might go and look at a proof to see how somebody else has done it. Like this book where they prove the Pythagorean theorem four different ways, so it makes more sense to see the different ways you could come to this conclusion. Also, it shows how I'm relating past knowledge about say the area of a triangle to this new or different concept. I guess it takes away like the magic and makes it more logical to me.*

Finally, P5 only related this idea of synthesis to creating helpful acronyms or diagrams.

> P5: *I don't know I connect a lot of key words or phrases and how they relate. Then, I use a lot of diagrams and acronyms to help me remember them or other ways of remembering ideas and how they relate to something else.*

Similar to the previous set of responses, participants responded in a more matter of fact way. Thus, it is likely that the skill of synthesizing information does not pose much of a problem for the participants. However, participants continue to reference and emphasize the importance of reviewing old mental models, conducting research, and reviewing related problems from new perspectives. This continues to show how important it is that engineering students find their own way of taking notes as well as the importance of having many examples of how to solve a problem and seeing topics from a variety of perspectives. Additionally, while instructors may be trying to improve students' problem-solving skills, it seems the participants value the difference in perspective over just having the right answer. Participants also seem to have a desire to understand what ways of solving a new type of problem are valid and how the theory of a new topic is put into practice. However, further investigation would be necessary to understand whether giving more example problems – versus students having to research their own additional examples – would be more of less beneficial to engineering students learning, as well as whether its influence on the development of mental models and their problem-solving skills.

Q11: How do you make judgements about the importance of concepts for a specific purpose or task, and to what extent do you use mental models, if any?

This question relates to the sixth hierarchical level of the cognitive domain *evaluation*, which focuses on an individual's ability to evaluate a concept or problem in a specific context [1].

Most of the participants, P1-P4, have some strategy for deciding what concepts are important; however, P5 stated that they are often unsure what will be covered on an exam. Thus, P5 said they often just review everything. However, P4 said they will generally ask instructors whether a concept or type of problem will be important in the long term and/or covered on a test, and P4 said professors would often tell them if it was important.

> P4: *I'll make a note so I can ask the professor the next time I see them, either in office hours or during class. I'll ask, "Is this really like necessary for the exam or just like for us to know how to do it?" And usually, most of the time they'll tell us like "Yeah, I just gave it to you guys for like a little background information. It's nothing too serious".*

This idea was echoed by participants P1 and P3 stating that sometimes people with experience will directly tell you a concept is important and/or professors will add it to their syllabus.

> P3: *I usually try to use the syllabus. If I'm already being told what the more important topics are, then I will definitely focus on that.*

The last major way participants, P1-P4, determined the importance of a concept was by how often the topic showed up on or was emphasized in their homework or practice problems, as well as how often it was discussed in class or in their notes.

> P4: *Usually, I'll go through the homework and the professor's notes, and I'll see what I used from their notes to do the homework and what wasn't used.*

Additionally, participants P3-P5 all made connections between the importance of a concept and whether it was going to be covered on an exam. Similarly, P3 and P4 made connections between the importance of a topic and whether it was covered in homework and how often it appeared in homework. Finally, P2 verbally said they had never thought of how to determine the importance of a concept; instead, P2 believes the importance of a topic is clear. However, after some thought, P2 noted that equations, diagrams, or other information instructors make a point to emphasize are what P2 commonly finds important.

> P5: *Honestly, I don't think I know what's going to be important on exams. I just review everything because I'd never know what's going to be asked. It's just very hard to know what's going to be asked, so I'm not quite sure what to study for exactly.*

Four of the five participants have minimal trouble determining a topic's importance; however, they did not show direct use of mental models when determining a concept's importance. Instead, participants said they often ask their instructors or are told which concepts are important for their future, whether that be for an exam or for use in their careers. The only connection to mental models, although indirect, was basing importance of a concept on how often a topic appeared in their homework, practice problems, notes, or class lectures, which are used by participants to develop their mental model in the learning process. On the other hand, P5 has little to no method of determining what topics are most important. However, further investigation must be conducted to determine if this is a common problem among engineering students. If this is a problem, there may be a few solutions. For example, perhaps P5 has had instructors that created homework and practice problems unrelated to their exams. In this case, instructors might need to be reminded that it is always a good approach to create homework and practice problems related to exam questions. This will help motivate students to complete the homework and practice problems and enhance their confidence to perform well in exams.

On the other hand, one participant (P2) may be an outlier, and most engineering students may not have a problem determining the importance of a concept, as most of these participants seemed confident in their methods to determine the importance of a concept. Either way, further exploration would be needed to show what the case is. Additionally, instructors should take into account that most participants mentioned relating importance to what is emphasized in in-class notes as well as individual notes, homework, practice problems, and what will be covered on a test when developing these class activities.

Q12: What learning approach do you think you learn best with and why?

Three participants, P1, P4, and P5, found the cognitive domain to be the best approach to learning, while P2 and P3 found the affective and psychomotor domain to be the best approach, respectively. However, it should be noted that most participants had some trouble picking one domain over the others, but P3 and P4 were more confident in their domain of choice than P1, P2, and P5. P1 found the cognitive domain best for taking in and understanding new concepts; however, they found a combination of all three domains to be very important. P1 also noted that sometimes which domain is most important depends on the subject being learned.

> P1: *That's really hard because I learn best with a combination of them, and its very subject dependent for me. I think overall, the one that catches the most subjects is the cognitive domain or mental models. But personally, I feel like a combination of these domains is important because maintaining motivation helps you execute that, and then sometimes having a physical reference or having somebody show you something physically helps you build those mental models better.*

Participant P2 has made clear that they do not often take notes, thus it makes sense that they would not find the cognitive domain to be the most important domain. Instead, participant P2 finds the affective domain to be the most important domain to learning.

> P2: *I feel like being motivated and excited to learn is probably the way that I am able to learn so much. Being able to create mental models of things is great and very helpful to learning anything, but I feel like the most important thing is just wanting to. I feel like if I didn't have that, then the other things wouldn't come along with it.*

Participant P3 found the psychomotor domain to be the most important as it directly relates to real life experience in engineering jobs. An excerpt from participant P3 is below.

> P3: *I would say that psychomotor is probably the most realistic. If we're learning something in college, and if we're learning all of that only on paper, and we* have no real-

life experience with that topic, we are not going to be successful when we get jobs out of college. We wouldn't be successful when we have to apply anything we've learned if we don't actually know how to apply it, especially as engineers.

P4 also noted that the cognitive domain is most important as it can be used to learn a wide range of topics, as well as aid in retention of information. P4 also stated that the cognitive domain is the primary domain they have used now. Finally, P5 referenced that they found the cognitive domain and mental models to be the best for doing well on exams.

P4: *I think mental models are the best because that's pretty much all I've used so far basically from freshman year of high school to now sophomore year of college and it hasn't failed me thus far. It's just really good because you're creating your own mental models that like unique to you. So, it kind of helps you with anything you're learning, and I've used it for all of my subjects or courses.*

P5: *Using the cognitive domain and techniques helps me a lot just because whenever I'm doing anything it's normally on paper and exams are formatted similarly on paper. Every class is on paper and taking exams is on paper, so definitely writing everything out helps me a lot.*

Overall, three out of five participants found the cognitive domain to be the most important or their preferred domain of learning, and four out of the five noted their appreciation for the cognitive domain, mental models, and taking notes. This shows the importance of the cognitive domain and mental models, and the importance of students learning how to take notes and develop mental models early in collegiate education. It also shows how important further research on this domain is. It should be noted that P4 said they chose the cognitive domain because they had not used the other domains. This might not be accurate, but it depends on the type of educational experience they have had. However, P3 and P4 are both sophomores, and P3 found the psychomotor domain to be the most important. Additionally, P3 was one of the participants most confident in their choice of domain. This may have been because P3 connected the psychomotor domain to real life and engineering jobs. It is also possible that P3 has had more interactive projects in college or high school. Also, a sophomore in engineering should have had some chemistry class with a lab component. Thus, it is possible that P4 has interacted with the psychomotor domain and active learning, but P4 might not have connected with that style of learning in particular.

Major Trends, Takeaways, and Implications

As a review of the findings and implications found in these 12 questions, the following section will focus on major trends, outlier responses, and their implications.

Other than participant P2, the remaining four participants typically need to take physical notes when learning new concepts as they build mental models. This shows how important taking physical notes is for students; however, all participants continued to say that taking notes has felt unnatural and difficult in their education. Therefore, it may be beneficial to have instructors in early collegiate classes teach students a variety of ways to take notes. This way students will have many examples to base their individualized way of taking notes on. Also, students will still need practice to develop their form of note taking and building mental models, as shown by participants in higher class standings having less trouble taking notes as they practiced taking notes or having less trouble taking notes than other participants. However, teaching this skill early on could make the learning process easier and more enjoyable, hopefully encouraging more students to continue their education in engineering.

However, participant P2 noted that they do not take physical notes outside of writing down important equations. Further research is required to determine whether this is common for a certain portion of engineering students to not take notes and what could be the reason for not taking notes. It would also be interesting to determine if this is common for certain engineering disciplines, why, and how lessons could be altered to aid in one style of learning or another.

When it comes to taking notes, many studies have been conducted. Although there is a wide history of studying how people take notes, a few sources were found that discuss some of the more impactful studies and papers written [30-32]. Of these sources, one discusses a variety of studies and theories about taking notes and how it may affect cognition and test scores in great depth [31]. It also brings to light important questions about the studies and theories discussed that should be considered in future research related to cognition and note taking [31]. This review also found studies that compare students that take notes to students that do not take notes [31]. However, it is predominantly comparing these groups' test scores instead of their mental thinking or qualitative reasoning for not taking notes [31].

Another study found specific practices instructors could implement to improve students' cognition through their notes [30]. For example, this study found that over half of students would like access to their instructors' slideshows so that they can more easily follow along and try to comprehend the notes instead of solely trying to write them down [30]. However, under half of the students have access to those slides [30]. It also found that only 15.3% of students would not take notes when they were given access to the slideshows [30]. Another source follows writing and note taking throughout humans' developmental stages and analyzes how technical language and language in general can affect peoples' notes and their cognition [32].

Another related question that has been studied is how cognitively difficult it is to take notes, what is the mental strain? This study found it to be cognitively difficult to take notes when learning as it requires a listener to comprehend the new information, select important points, and record those points, all while having limited time [33]. Thus, future research may be interested in investigating the pacing of a class as it relates to how difficult it is for a student to take notes. Finally, others have reviewed studies on the impact of guided notes for students [34]. This is similar to the discovery that few students will not take notes when they are given access to an instructor's slideshow, which is like a set of guided notes [30], [34]. Future researchers should review related research, take notes on how to improve it, and see how specifically undergraduate engineering students today would respond.

When it comes to further research on how to teach undergraduate engineering classes better and improve students' learning process and mental model creation, there were a few additional trends found in the data. First, participants' prolific need for additional examples, repetition, hearing other explanations or perspectives, and having concepts related to other concepts. These concepts were collectively mentioned by participants over fifty times throughout their interviews. Additionally, most times these ideas were mentioned, participants noted having to do their own additional research outside of class to find these things and deepen their understanding of the current topics they are learning. While research experience is an important skill for engineering students, many of the participants also indicated their concern of learning things incorrectly from inaccurate sources online. Therefore, instructors might want to add more helpful resources, references, examples, diagrams, and connections to other concepts for students to reference and practice. This way students will have a reliable source to review additional perspectives, examples, and practice problems.

A few sources were also found that recognize the importance of additional examples, demonstrations, and perspectives and/or found them to be helpful for students [9], [11], [20]. Also, when participants are developing their mental models, they often indicate a preference towards finding similarities between concepts whether that be synthesizing a new mental model with older mental models, researching a new concept, or so on. Thus, instructors that emphasize similarities between new and old concepts may help their students learn quicker and with a deeper understanding.

Additionally, participant P2 brought up an interesting point when it comes to repetition and practice, specifically when it comes to grading homework. While all participants saw the value in practice, P2 greatly dislikes how most homework is graded for accuracy on a student's first try as it puts more focus and stress on getting the answer right the first time and getting a good grade, versus putting the focus on learning and understanding how to do a problem correctly. Therefore, P2 would rather have homework be given for participation and to focus on learning. Engineers in the field must be able to apply math and engineering concepts safely and accurately, but they are able to make tests, run analytic software, and have other engineers to check and debate each other's work. Instead, it might be interesting to test how homework for participation, homework valued at a lower overall grade percentage, homework with multiple attempts, and so on may affect final grades and overall learning.

While there are many studies relating to homework, some have found that there is much less literature on the conditions most likely to improve the quality of students' homework and grades at the collegiate level [35]. Many studies surrounding the topic of homework are conducted on pre-collegiate levels and/or focus on different aspects of homework, such as completion over quality [36]. On the other hand, one more applicable study also found that giving credit is generally necessary to improve homework quality [35]. However, they also acknowledge that this may not be true for non-psychology majors and/or classes that are not similar to their sample's class set up [35]. Another applicable literature review found was a detailed master's thesis [37]. This literature review did not review assigning homework for participation: instead, it found more in terms of things to consider when creating homework [37]. For example, it found that higher grades were more correlated with more time spent on homework [37]. However, it did recognize that each student has their own ideal learning environment that may not be accommodated for because it is not the standard widely accepted learning environment [37]. This furthers the idea that more research on undergraduate engineering homework assignments – assigning homework in general – needs to be conducted.

This research made it apparent that more research needs to be conducted to clarify what statements are actual trends and which are outliers. It will also show trends as they relate to engineering disciplines and/or other demographics. These trends would be valid starting places for additional quantitative and qualitative research to be conducted which may determine the most and least effective teaching strategies with a focus on cognitive domain of learning, hopefully making learning engineering easier and more enjoyable to students.

Conclusions

In this qualitative study, five participants were individually interviewed online and asked to respond to 32 open ended questions related to the cognitive, affective, and psychomotor domain. These interviews were transcribed and coded to organize and find trends within their responses. While all participants valued mental models, only four of the five participants felt the need to develop physical notes when learning new concepts. All participants seek out additional examples, perspectives, connections between concepts, and greatly value practice. However, participants also acknowledge that they must conduct additional research outside of class to find these things while worrying about the validity of this information found on the internet. Additional quantitative research is necessary to determine whether these findings are common, how these trends may relate to students' engineering disciplines and demographics, and which teaching methods will maximize students' learning and minimize frustration and confusion with a focus on cognitive domain of learning.

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