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Considering the Whole Learner: A Theoretical Examination of Learning and Individual Identity using Cognitive Load Theory

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Abstract

Cognitive Load Theory (CLT) is a foundational framework in educational psychology that explains how learners process and manage information. As engineering programs face growing challenges in student retention and engagement, CLT offers an evidence-based approach to enhance learning efficiency. This paper introduces key concepts essential to applying CLT effectively and proposes a promising research direction for extending its use to also support greater inclusion in engineering education. Research shows that students from minoritized populations in engineering experience more stress and anxiety than their peers from dominant groups. To date, most studies have approached this issue from sociocultural perspectives, such as stereotype threat and sense of belonging. However, limited research from a cognitive lens has also revealed that course redesigns to reduce extraneous load have a greater impact on the performance of minoritized students than their peers. This finding suggests that heightened stress and anxiety can burden working memory, increase the risk of cognitive overload, and limit student learning and knowledge retention. This study repurposes qualitative data from interviews with engineering students to examine how identity-related challenges contribute to cognitive load. Although the original interviews did not address cognitive load explicitly, analysis reveals numerous instances in which students experienced mental fatigue, excessive cognitive demand, and various forms of cognitive load due to marginalization, imposter syndrome, and code switching, and stereotype threat. By reviewing the foundational principles of CLT and examining student experiences connecting identity-related factors to learning, this work highlights the urgent need for research that transfers CLT's principles into this domain and positions it as a potential lens for addressing systemic inequities in engineering education.

Introduction

Efforts to diversify the engineering workforce have seen limited results. This lack of success warrants a deeper examination of the experiences of diverse engineering students during their education. While prior work from the authors has shown that students separate their minoritized identities from their engineering identities [1], identity scholarship has long established that students' experiences, activities, relationships, and environments outside the classroom can significantly influence how they engage with, interpret, and learn material in the classroom.

One potential reason behind the limited diversification of the engineering workforce could be the tendency to acknowledge only the social and psychological effects of marginalization instead of looking at cognitive effects on student learning, thereby only considering one aspect of the learner. This paper considers the whole learner using a method known as "thinking with theory" [2] to theoretically examine the implications and impacts of navigating marginalized and minoritized identities in engineering while attempting to learn engineering course content. Thus, this theoretical examination underscores the need for engineering educators to consider the

identities of their students in their teaching, even if these identities do not become explicitly apparent in the classroom.

This paper draws on data from a larger research project that has developed audio approaches to enhance faculty understandings of equity and inclusion by disseminating narratives of students with minoritized identities in engineering education. While study details, including data collection and analysis procedures, are explained elsewhere [3], this paper focuses on an analysis of these student narratives through the framework of Cognitive Load Theory (CLT). CLT is a well-established theory in educational psychology that attempts to optimize learning through the management of mental resources [4]. By examining student identities through this lens, the authors encourage engineering educators and researchers to discover new strategies that view enhanced learning and inclusion not as competing goals, but as mutually reinforcing. Research shows that CLT-informed interventions can disproportionately benefit students from minoritized backgrounds [5], and related studies have linked CLT to factors such as stress and emotional [6], suggesting powerful opportunities for inclusive course design.

An understanding of terms closely related to cognitive load is required to properly articulate and address the cognitive effects of identity related challenges. For example, strategies designed to reduce cognitive load are ineffective if the cognitive demand of a task is too high, so any attempt to solve these challenges must be preceded by an accurate recognition of the issue. Consequently, the authors begin by outlining CLT, defining related terms, and identifying a limitation of CLT exacerbated by viewing data focused on identity. Afterward, they present their theoretical intersection of identity challenges with CLT by providing examples from the experiences of students.

General background of CLT

Cognitive Load Theory (CLT) is based on the assertion that all individuals have a limited working memory, and cognitive load can be defined as the amount of information stored in it. CLT breaks cognitive load into two main categories: intrinsic and extraneous. Intrinsic load refers to the “complexity of the information being processed”, or the difficulty of the subject to be learned. Extraneous load refers to “how the information is presented and what the learner is required to do by the instructional procedure,” or inefficiencies in how the material is being learned, such as poor instructional design [7].

When cognitive load is too high, learning becomes more difficult, as cognitive resources are diverted to processing complex material and inefficient learning strategies and away from the construction of knowledge in long-term memory. Despite the potential for improving learning, especially in technically complex fields, CLT is often underutilized or ignored in the field of engineering. A likely reason is the emphasis of domain expertise at the expense of pedagogical training, but cognition and information processing are also highly complicated fields with many similar terms that might seem synonymous. Terms such as cognitive demand, mental effort, cognitive resources, and mental fatigue are all related to cognitive load, but they are each distinct

and refer to slightly different concepts. The following section explains each of the aforementioned terms with greater detail.

Clarification of Terms

Cognitive Demand

Cognitive demand is the intellectual difficulty of a task and is therefore highly related to intrinsic cognitive load. Intrinsic load refers to the elements held in the working memory due to the complexity of the task while cognitive demand refers to the level of conceptual understanding required to complete the task [8]. For example, the two math problems shown in Figure 1 are both difficult to solve without writing anything down.

Problem 1. $312 \times 65 = ?$ *Problem 2.* $f(x) = \frac{3x-2}{x}$ $f'(x) = ?$

Figure 1. A basic multiplication problem with high cognitive load (left) and a basic calculus problem with high cognitive demand (right).

Problem 1 is a simple multiplication problem, but due to the high number of elements, it is difficult to solve without writing it out. This indicates a high cognitive load despite low cognitive demand. Problem 2 is a calculus problem that would be simple for a calculus teacher but very difficult for a student who is new to calculus. This indicates a high cognitive demand but a low cognitive load. In fact, a calculus teacher would likely find problem 2 easier to solve in their head, even though many math students would identify it as the "harder" problem.

Mental Effort

Mental effort is the cognitive resources actively devoted to the task [9], meaning that any distractions from the task would increase the cognitive load of the student but would not increase their mental effort. This is often an area where students with minoritized identities might be at a disadvantage, and a low amount of mental effort could indicate a high amount of peripheral cognitive load. For example, if a woman attends a lecture and finds that she is the only woman present, she might struggle to maintain the level of mental effort required to understand the material. Maybe she is only internally distracted, maybe her neighbors distract her by bringing it to attention or even openly engaging in flirtation, or maybe she is entirely unaffected by the situation and can focus as required.

While its effects on learning are apparent, cognitive load is difficult to directly and objectively measure. Therefore, many researchers use subjective methods, often employing psychometric scales [10]. One difficulty is that students are often not familiar with the term cognitive load, so despite the aforementioned differences, perceived mental effort is often used as a measure of cognitive load [11].

Cognitive/Mental Resources and Cognitive Capacity

In the context of CLT, cognitive or mental resources refer to a person's total mental processing power [7], [12]. It could be said that cognitive load is the total amount of mental resources that are being used at any given time. While cognitive load can be managed and the total cognitive load of an individual can change depending on subject complexity and instructional techniques, every individual has a set amount of cognitive resources, known as their cognitive capacity. While cognitive capacity is continuously increasing during an individual's cognitive development [13], in short time periods it can only be decreased (i.e., through mental fatigue) or restored to the normal amount. This is in line with research proposing that we have a limited amount of working memory that can be used at any given time [14]. Working memory, cognitive resources, and mental resources could all be used interchangeably in most circumstances.

Mental Fatigue

Mental fatigue is something that people unfamiliar with this field often confuse for cognitive load, but they actually refer to two entirely separate, but related, phenomenon. Mental fatigue is when a person feels a lack of motivation and/or a decrease in their available cognitive resources [15]. This is often caused by long hours without breaks, factors external to learning such as sleep or health, or excessive cognitive overload. The latter potentially being the reason mental fatigue is often confused for cognitive load. In other words, experiencing a high level of cognitive load for an extended duration is a very common cause of mental fatigue, but strategies that aim to reduce cognitive load have little to no effect on someone who is already experiencing mental fatigue, and to fully solve those issues, a different set of solutions are needed than what is required to reduce extraneous cognitive load.

Limitations of CLT for Identity-Based Theories

One distinction integral to this paper is that extraneous load is historically defined in relation to instructional design [4], [16], rather than any cognitive load not essential to learning. Under this distinction, any additional cognitive load not related to inherent complexity or instructional design is uncategorized. This is not an issue under the assumption that the entirety of a student's cognitive capacity is devoted to the learning task at all times, but of course, this assumption is an ideal that can never be realized.

Recently, researchers have begun to recognize this limitation and have expanded the definition of extraneous load to include aspects of the learner and learning environment, such as intrusive thoughts or distracting information in a classroom [17], [18]. However, most attempts to measure extraneous cognitive load entirely ignore this aspect of extraneous cognitive load [10], [19], [20], despite its potentially huge effect on learning.

To remedy this shortcoming, this paper will refer to any cognitive load related to instructional design or learning tasks as extraneous load, and any load unrelated to inherent difficulty or

instructional design as peripheral load. Peripheral load technically fits under the more recent definitions of extraneous load and can therefore be considered a subcategory of extraneous load, but to avoid confusion, this paper will treat them as entirely different categories of cognitive load. Most often, this paper discusses peripheral cognitive load that originates from issues related to identity; however, anything else that might add to the cognitive load of a student during class, assignments, or exams would still fall into this category of peripheral load. This could include something like a distracting classmate, technical difficulties, or even a recent death in the family.

Qualitative Analysis of Peripheral Cognitive Load

During the larger study, interviewers asked students about the interaction between their marginalized identities and their education as engineering students. After the interviews, the researchers assigned pseudonyms and created narratives based on the lived experiences of the interviewees. At no point during the original study was there a focus on, or even mention of, cognitive load. Despite this, there are many easily identifiable instances where students are clearly experiencing an increase of cognitive load due to phenomenon commonly associated with minoritized identities such as marginalization, stereotype threat, imposter syndrome, and code switching. By repurposing this dataset, the current analysis explores how these factors contribute to minoritized students experiencing negative cognitive effects like mental fatigue, excessive cognitive demand, and all three types of cognitive load, shedding light on the often-overlooked cognitive burdens of identity related challenges.

Marginalization

Marginalization is an extremely broad term that covers many different types of discrimination and exclusion. It can range from short comments, like the following presented by Amber, to extremely debilitating systemic oppression that profoundly impacts an individual's opportunities, well-being, and sense of belonging.

> One time when I was taking Calc II, one of my peers basically said the professor favors female students over male students. And they were kind of rude, like, "oh, you're not actually that smart. The only reason why you got those high grades was that the professor likes girls." Stupid! I was like, "what a way to belittle both my academic success and my identity all in one swoop". It was just an offhand comment, but I remember it pretty well. I guess just some of these things stick with you, even though he probably doesn't remember saying it. I was just good at the class; there's no reason to think that I was schmoozing my way up to the top or whatever.

Despite being a fleeting comment that the offender likely forgot, Amber dwelled on this accusation long enough to remember it several months or years later during an interview. This emphasizes that even subtle forms of marginalization can leave a lasting impact. While she does not mention the effect on her ability to concentrate during class, it likely increased her peripheral load by a substantial amount and could have led to mental fatigue and limited her mental effort for the rest of the day.

Alice discusses her experiences as an international student after spending some time attempting to find an internship. Companies are often hesitant to hire international students because they are required to sponsor them, meaning extra expenses in time and money while the employee goes through visa processing.

> (Alice:) So it gives you that extra pressure to be the best in your class because you're at this huge disadvantage compared to everyone else. So if I'm not the best, if I'm not the most studious, highest graded student, there's no way someone's gonna look at my resume. There's no way that after I graduate, I'll be able to stay in this country. It's a psychological pressure on you the whole time. You have to be the best, you have to excel above everyone else. Otherwise, obviously, they're going to choose them over you. It's a very, very unfair race.

This quote is a clearly portrays how her status as an international student contributes to her peripheral cognitive load in the form of a constant "psychological pressure." The additional obstacles imposed on international students finding employment are completely beyond the control of engineering faculty, and yet they can hinder their students' learning regardless.

Imposter Syndrome

Discussing processes and answers with peers is a technique that is often used in an attempt to help students understand the material better, but for George, who has ADHD and social anxiety, this technique tends to undermine his learning. He struggles to stay focused for the entire class time due to his ADHD, so when asked to discuss with peers, he is often unable to meaningfully participate, leaving him feeling like he doesn't belong.

> (George:) Particularly, in classes where we do a lot of discussion, we'll be asked to discuss with people around us. And a lot of times, it feels like there's this extra pressure put on my back to get it right or know what the answer is supposed to be, even when, in theory, it's just a discussion… And it's like when I'm not contributing answers in a group discussion, they'll get frustrated with me. So, I get frustrated that I'm not contributing to the work and helping out, whereas they don't understand or see that, it's actually just a mental struggle to be able to express it to them and to say like, what I feel and come up with the right answer.

This example highlights the importance of managing peripheral load. Many students feel like an imposter. This can lead to high amounts of pressure and anxiety during school, and this can be exacerbated if they feel unable to keep up during lectures and learning activities. This additional stress can increase their peripheral load even more, leading to a downward spiral. While this might sound like an extreme example, this is the exact scenario described by another student named Jane.

> (Jane:) I started community college feeling like a smart kid, almost a straight-A student from high school around 2018. And then, in college, I was not succeeding

> as much as I expected. Like I would go to class, and I would study, and nothing was making sense. So, that was putting stress on me. I was anxious all the time. Like, am I meant to be an engineer? Should I really be doing this? Am I good enough? A lot of imposter syndrome, for sure. All of those thoughts that went through my head constantly that made me anxious and depressed to the point of going and getting my anxiety diagnosis.

While not a complete or permanent solution, having teachers that know how to help Jane manage her cognitive load during class could enable her to succeed more in her academic endeavors and break out of the negative cycle rather than aggravating it every time she attends class.

Code Switching

The following example provided by Jakobe, a first generation Black student, could be relevant to anyone whose family is uneducated, speaks a different dialect of English like AAVE, uses English as a second language, or just feels the need to alter their speech patterns to be more formal while attending school. This phenomenon is known as code switching (CITATION) and would put an additional peripheral cognitive load on these students anytime they speak in class.

> (Jakobe:) I feel as if I operate in both worlds. When I am in my community, I speak the way I normally do. And when I am out of my community and in a more professional environment or around people who are not from my community, I change my language a bit.

Code switching is often displayed through language, but it can also manifest in a variety of other circumstances. Whether conscious or unconscious, code switching occurs any time a student is putting on a performance for others by altering speech, behavior, or appearance. Another example is provided by Jane.

> (Jane:) I have diagnosed anxiety and depression, and those are things that I struggle with everyday… I think that with everything that I deal with, I have found ways to mask in front of anybody else in the way that they see me.

Any of concentration or effort spent masking aspects of herself is concentration or effort that is not directed toward learning. The simple answer is to create a safe space where students do not feel the need to perform. Unfortunately, this “simple” answer is incredibly complicated and difficult to execute successfully.

Stereotype Threat

Deborah, a black student, expressed that she is often one of the only black individuals in her classes. Because of this, she sometimes feels as though she is a representative of her race, and that those around her will judge all black people based on their experiences with her.

> (Deborah:) So you don’t want to ask certain questions in class, even if you really need to know because you don’t want to be perceived as dumb. Cause if they

> think you're stupid then they might think, "Oh, all black people are stupid." Not everyone thinks like that, but it still happens. And even if no one says that to you, it's something you feel.

While not stating it explicitly, Deborah's statement of "but it still happens" alludes to previous experiences where her worries have been proven accurate. However, any student that worries about this, whether or not they have reason to worry, is going to experience an increase in peripheral load that will detract from their learning experience. Beyond that, Deborah has questions that are going unanswered, which will likely cause her to fall even further behind whenever she experiences this fear to ask questions.

Other Examples

While the next two quotes could likely fit within another category, such as marginalization, they are more related to unfortunate circumstances than systemic inequity. Alice shares another aspect of her experience as an international student.

> (Alice:) The first time I realized I had a disadvantage was in my first college physics class. I don't know if this is because I'm international or because I moved around so much, but [I was utterly lost]- the class was hell, I had to learn high school physics and college physics all at the same time. It was my first semester in the college, so I had no idea about resources that were available to me.

Because of a different background, Alice was required to learn subject material the other students already knew while simultaneously trying to learn the course material as well. This is a perfect example of how identity can impact any type of cognitive load, even intrinsic. At first, this scenario seems unique to international students, but another student described something very similar. Jakobe is a first-generation student who attended community college for two years before transferring to a four-year university.

> (Jakobe:) When I transferred from community college to the university, I had a disadvantage compared to other students… I did all the coding classes the year before I transferred, so I had to actively relearn everything that, for others, was still fresh. And I had to keep up with what was being taught in my classes to no longer feel left behind.

Once again, the student is trying to learn the material while simultaneously learning the foundational knowledge. Another way to describe this phenomenon is that the cognitive demand is slightly too high for the students to effectively learn the material due to their lack of foundational knowledge. While this is mostly out of the control of faculty, any attempt to understand their students' current knowledge of the subject can reduce the negative effects of this situation.

Implications and Future Work

These examples can help engineering professors better understand the social, psychological, and cognitive challenges frequently confronted by the minoritized students, because there are probably many similar instances happening regularly in their classrooms. However, these challenges are often unique to the individual and circumstance, so this should not replace any attempts to personally understand their own students. Providing safe ways for students to inform faculty about experiences such as those provided is the often the first step to finding a solution.

CLT has long been accepted as a potential way to increase student learning, especially for technically challenging fields. Historically, CLT has focused almost exclusively on reducing extraneous load because the only reliable way to reduce intrinsic load is by increasing background knowledge, or in other words, learning the subject material. Even long before CLT, instructors prioritized decreasing intrinsic cognitive load; this is why elementary level classes do not teach advanced mathematical theory. Instead, students start with the basics and eventually reach more inherently difficult topics.

As the reduction of intrinsic load is already common practice, CLT expands the focus to include the reduction of extraneous cognitive load by improving instructional design. While this is an effective and important approach, it ignores some other sources of cognitive load that could also be minimized. This oversight risks perpetuating inequities by failing to account for the unique cognitive challenges faced by marginalized students.

Significant research has been done to explore how marginalization can be minimized in the classroom, but that research is generally viewed through the lens of equity and inclusion instead of cognition. However, as shown in this paper, marginalization and identity related concerns also have a cognitive effect on students. Therefore, the approaches used to minimize marginalization could potentially be just as effective for improving the learning of students in minoritized populations as the techniques described by CLT to reduce extraneous cognitive load. Alternatively, instead of focusing on external factors like challenging environments and circumstances, another potential solution could involve teaching students internal techniques, such as mindfulness [21], to manage their peripheral load, which has proven effective in reducing other forms of extraneous cognitive load [22].

Conversely, CLT traditionally conceptualizes total cognitive load as additive, meaning any decrease in intrinsic or extraneous load similarly decreases total load, so a decrease in extraneous load will still help a student struggling with a large amount of peripheral load. Consider an overly simplistic illustration, where an arbitrary value of 10 total cognitive load means cognitive overload, thereby greatly hindering a student's learning. If a student's current intrinsic, extraneous, and peripheral loads are all at a value of 4, then their total load is 12, indicating cognitive overload. A decrease in any type of load by 2 would put them within the acceptable limits of their cognitive ability, and the type of load decreased would not matter. By this logic,

using known CLT effects to decrease extraneous cognitive load might help a marginalized student just as much as decreasing their peripheral load.

All of the statements above rely on the assumption that peripheral load has the same effects on student learning as intrinsic and extraneous cognitive load. This assumption seems likely but must be validated by research. Therefore, next steps in this research include looking at 1) valid and reliable ways to measure peripheral cognitive load, 2) the effects of techniques that decrease marginalization on the peripheral cognitive load of students, and 3) if the effects of known techniques to reduce cognitive load are more effective for students from marginalized populations.

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