Exploring Faculty Perspectives on Challenging Threshold Concepts in Structural Engineering

Adeed Khan, University of Nebraska - Lincoln
Dr. Logan Andrew Perry, University of Nebraska - Lincoln

Dr. Perry is an Assistant Professor of Engineering Education in the Department of Civil & Environmental Engineering at the University of Nebraska-Lincoln. His work contains a unique blend of engineering education and civil engineering projects. Dr. Perry's current work centers workplace readiness, broadening participation, and construction safety education.

Prof. Jacob Henschen, University of Illinois Urbana-Champaign

Professor Henschen completed his B.S., M.S., and PhD. at the University of Illinois Urbana-Champaign in 2007, 2009, and 2018 respectively. He was an Assistant Professor at Valparaiso University until he moved to the University of Illinois Urbana-Champaign as a Teaching Assistant Professor in June 2020. He serves as the co-chair for the Teaching Methods and Education Materials Committee at ACI and the co-chair of the Committee on Faculty Development at ASCE.

Prof. Ann C Sychterz Ph.D., P.Eng, University of Illinois at Urbana-Champaign

Ann Sychterz (SICK-tesh) is an assistant professor in the Department of Civil & Environmental Engineering at the University of Illinois Urbana-Champaign. With her team at SMARTI lab, they harness geometrically nonlinear systems, such as tensegrity structures and origami, for adaptive civil infrastructure. She obtained her PhD in 2018 from the Swiss Federal Institute of Technology Lausanne (EPFL) addressing the novel use of control algorithms, statistical diagnostic tools, and real-time feedback on a full-scale tensegrity structure to enable smooth deployability, damage detection, adaptation, and learning. She completed her masters and bachelors of science at the University of Waterloo, Canada. Dr. Sychterz completed a postdoctoral position at the University of Michigan on actuator optimization of adaptive origami structures. She has funded projects by the National Science Foundation, the Illinois Department of Transportation, and the Swiss National Science Foundation.

Exploring Faculty Perspectives on Challenging Threshold Concepts in Structural Engineering

Abstract

This study investigates the threshold concepts in structural engineering that faculty members identify as the most challenging for students to grasp. Threshold concepts are transformative, fundamental ideas that serve as gateways to deeper understanding within a discipline. Once these concepts are fully understood, students experience a significant shift in their ability to apply knowledge and solve complex problems. These concepts are not just essential for mastery; they often lead to a "cognitive leap," changing the way students think about and engage with the subject. However, because threshold concepts are inherently complex, they can also present significant barriers to learning. Students may struggle to comprehend these ideas fully, which can hinder their progress in both understanding and applying core structural engineering principles. Overcoming these barriers is crucial, as grasping threshold concepts is often key to moving forward in the discipline and developing the expertise needed for professional practice. Mastering these ideas is essential for gaining deeper insights into structural engineering and successfully navigating its technical and theoretical challenges.

Using semi-structured interviews with faculty at R1 institutions in the USA, this qualitative study identifies the specific challenges students face, including gaps in foundational knowledge, misconceptions, and difficulties with abstract concepts like internal forces and load paths. The findings emphasize the need for innovative teaching strategies, such as augmented reality tools, hands-on learning opportunities, and asset-based teaching approaches, to address these barriers. By implementing these strategies, educators and curriculum designers can enhance structural engineering education, helping students overcome learning obstacles and better prepare for professional practice.

Keywords: Threshold concepts, Structural engineering and Faculty perceptions

I. Introduction

An understanding of threshold concepts in structural engineering is essential for improving students' learning experiences and ensuring their professional success. These concepts are defined as transformative, integrative, and often troublesome for learners, as they represent pivotal ideas that fundamentally change the way students understand a subject once mastered [1]. They lead to a significant shift in comprehension and allow students to integrate separate ideas into a unified framework. However, because these concepts are inherently complex, they often present significant barriers to learning [2].

Structural engineering, a specialized branch of civil engineering, requires a deep understanding of theoretical knowledge combined with practical application. This field demands knowledge from disciplines such as physics, mathematics, and materials science, making it particularly challenging for students [3]. Faculty members frequently observe that students, especially in their third and fourth years, struggle with foundational concepts such as structural analysis and material behaviour under varying conditions. These struggles highlight the critical role of threshold concepts in helping students develop the expertise needed for both academic and professional success.

In structural engineering, these concepts often involve core principles such as how structures respond to different forces, including tension, compression, and shear. Understanding these forces is essential for designing structures that are safe, stable, and efficient [3]. However, students often find these ideas challenging due to their abstract nature, which makes visualizing and applying them in real-world contexts difficult [3]. Understanding how different forces interact with various materials and design elements can be a challenging and often counterintuitive task for students new to the field [2].

The concept of foundational knowledge is also essential when discussing students' ability to grasp threshold concepts. Foundational knowledge refers to the existing understanding that students bring to their studies, which can either facilitate or hinder their ability to learn new and complex material. In structural engineering, foundational knowledge in subjects such as mathematics and physics is crucial for comprehending threshold concepts. Many students begin their studies with misconceptions or gaps in foundational knowledge, particularly in areas such as calculus and mechanics, which makes it more difficult to grasp advanced topics like material behaviour under stress [4]. Without a strong foundation in these areas, students are often unable to achieve the cognitive leap required to fully understand and apply threshold concepts [5].

The importance of mastering threshold concepts in structural engineering cannot be overstated. Faculty members frequently report that students struggle with key ideas, particularly when it comes to applying theoretical knowledge in practical situations. Concepts such as how materials behave under different types of loads—dead loads, live loads, and environmental loads—require a deep understanding of physics and materials science, which is not easily acquired through traditional teaching methods [3]. These difficulties highlight the need for innovative teaching approaches that help students overcome the barriers to understanding these transformative ideas. Once students grasp threshold concepts, they are able to integrate separate pieces of knowledge into a cohesive understanding, which is essential for solving the kinds of complex problems encountered in real-world structural engineering [2].

II. Literature Review

The concept of threshold concepts in education was first introduced by Meyer [6] and has since become a significant area of study in various disciplines, including structural engineering. These concepts are seen as gateways to deeper learning, allowing students to apply theoretical knowledge in practical, real-world scenarios. However, mastering these concepts presents several challenges due to their complexity and the abstract nature of the subject matter [2].

One of the key characteristics of threshold concepts is their transformative nature. Once students fully comprehend a threshold concept, their understanding of the subject changes fundamentally. This shift allows them to see connections between previously unrelated ideas and apply their knowledge in new ways [1]. In structural engineering education, students often move from learning isolated principles—such as material strength or load distribution—to developing a more integrated understanding of how these elements interact within complete structural systems. However, traditional teaching methods often emphasize analysis of discrete members, making it difficult for students to visualize load paths and the behavior of entire structures in three-dimensional space [3]. For example, a student might initially learn about the properties of steel or concrete in isolation but mastering the threshold concept of load path analysis allows them to understand how these materials behave under different loads in a complex system. This shift in understanding is crucial for students to transition from theoretical learning to practical application, a key component of professional engineering practice [2].

Another essential aspect of threshold concepts is their integrative function, which allows students to unify disparate pieces of knowledge into a cohesive whole. In the context of structural engineering, this often involves bringing together knowledge from mathematics, physics, and materials science to understand how structures behave under various forces [3]. For example, understanding how a bridge supports its own weight and additional loads such as traffic or wind requires students to integrate their knowledge of material properties, force distribution, and environmental factors. Without mastering this integrative process, students are likely to struggle with advanced engineering problems that require them to balance multiple factors simultaneously. The integrative nature of threshold concepts is particularly important in structural engineering, where real-world problems are often complex and require holistic solutions [6].

However, despite their importance, threshold concepts are often troublesome for students to master. The difficulty lies in the abstract nature of these concepts, which can make them challenging to visualize and apply. Traditional teaching methods, which often rely on two-dimensional diagrams or static models, may not adequately convey the dynamic and multi-dimensional nature of structures [3]. This can result in a fragmented understanding of key principles, making it difficult for students to apply their knowledge in real-world scenarios. For instance, while students may be able to calculate the forces acting on a structure in a classroom setting, they may struggle to apply this knowledge when faced with a more complex, three-dimensional structure in a professional context. The abstract nature of threshold concepts in engineering thus presents a significant barrier to student learning, which educators must address to improve educational outcomes [5].

One way to address these challenges is through the use of innovative teaching strategies that help students better visualize and understand threshold concepts. For example, augmented reality (AR) has been proposed as a tool for teaching structural analysis, as it allows students to interact with three-dimensional models of structures in real-time [3]. By visualizing how forces act on different components of a structure, students can develop a more intuitive understanding of how these forces interact in the real world. This approach can help overcome some of the limitations of traditional teaching methods, which often fail to convey the complexity of three-dimensional structural behaviour. By using AR and other interactive tools, educators can help students bridge the gap between theoretical learning and practical application, thereby improving their ability to master threshold concepts [3].

In addition, educators must also focus on misconceptions that students may bring into the learning process. Misconceptions in engineering education whether in transportation, structural design, or other fields can prevent students from effectively engaging with threshold concepts, even when they have a solid foundation in related technical subjects [5]. For example, a common misconception is that structures only need to be designed to withstand static loads, when in reality, structures must be able to withstand dynamic forces such as wind or earthquakes. Addressing these misconceptions through targeted instruction and hands-on activities can help students overcome these barriers and achieve a more accurate understanding of threshold concepts [5].

Ultimately, the mastery of threshold concepts in structural engineering is critical for students to succeed both academically and professionally. These concepts not only transform students' understanding of the subject but also enable them to integrate knowledge from different areas and apply it in real-world situations. However, the abstract and complex nature of these concepts and the presence of misconceptions, makes them difficult to learn. By recognizing these challenges and developing innovative teaching strategies, educators can help students overcome these barriers and achieve the cognitive leaps necessary for success in structural engineering [3].

Research Purpose

The purpose of this research is to explore the threshold concepts in structural engineering that faculty members perceive as the most challenging for students to understand. This qualitative study investigates instructor perceptions of the challenges students face in grasping complex concepts and explores how misconceptions impact their understanding. Participants include faculty members teaching structural engineering at R1 institutions in the USA, with interviews conducted to gather insights. The findings aim to provide valuable insights for educators, curriculum designers, and academic administrators to develop more effective teaching methods, refine curriculum design, and better support students in mastering critical structural engineering concepts.

III. Research Question

Research question addressed in this study is:
What threshold concepts do faculty perceive to be the most critical in undergraduate structural engineering?

IV. Methods

This study employed a qualitative research design to explore the perspectives of faculty members regarding threshold concepts in structural engineering that students find most challenging. The research aimed to gather in-depth insights into how faculty members identify these concepts, the difficulties students face, and potential strategies to improve teaching approaches for better comprehension.

Participants and Setting

Participants included five faculty members from structural engineering programs, selected based on their experience teaching core courses that involve threshold concepts. All interviews were conducted remotely via Zoom, allowing flexibility in participation while ensuring consistency in data collection. The study targeted faculty actively engaged in teaching to ensure current and relevant perspectives.

Data Collection

Data was collected through semi-structured interviews, which allowed faculty members to discuss their views on the challenges students face with threshold concepts. The interviews, lasting approximately 30 minutes each, were audio-recorded with participants' consent and later transcribed for analysis. Questions focused on faculty observations of student struggles, the significance of threshold concepts for professional practice, and teaching strategies aimed at facilitating student comprehension.

Data Analysis

Thematic analysis was applied to the interview transcripts to identify recurring themes and patterns related to faculty perceptions [7]. This method enabled the research team to systematically explore faculty insights and categorize key themes such as the impact of foundational knowledge, the complexity of threshold concepts, and effective teaching interventions.

V. Results & Analysis

The analysis of the structural design and engineering concepts highlighted seven key themes (or concepts) that defined the challenges and learning areas for students. Each theme reflects a critical aspect of structural design that influenced how students approached and understood the concepts.

Forces and Structural Analysis

One of the foundational concepts in structural engineering is analyzing forces and moments within a structure. This involves using free-body diagrams to isolate individual components and visualize the forces acting on them. While students generally grasp external reaction forces due to their more straightforward nature, understanding internal forces is significantly more challenging. Internal forces represent the stresses and strains within a structure that cannot be directly observed or "felt," making them more abstract.

As one instructor noted, *"They know how to find the reaction forces. They can feel the reaction force. But for internal force, it's hard for a student to visualize or to feel the internal force."* - Participant A. This difficulty often hinders students from developing a deeper understanding of how forces are distributed within a system.

To help students overcome this challenge, educators can introduce tools such as animations or simulations that illustrate how internal forces propagate through a structure. Real-world examples, like observing the internal forces in a beam under load, can also help bridge the gap between theory and application.

Load Transfer and Flow

Load transfer refers to the way forces move through a structural system from where they are applied to where they are ultimately supported. For instance, in a building, loads are transferred through floors, beams, columns, and foundations. Understanding this process is essential for designing structures that are both safe and efficient. However, students often struggle to trace these load paths, particularly in complex systems with multiple layers of force distribution.

One faculty member explained, *"Students don't understand how the load moves through the system. They struggle to trace the load path through a diaphragm to the supporting members."* - Participant B. This confusion arises because load paths are not always intuitive and require a solid grasp of how structural elements work together.

To address this, teaching methods could include physical models that allow students to see how forces travel through different components. Digital tools, such as 3D structural analysis software, can also provide an interactive way to visualize load flow, helping students make connections between theory and real-world systems.

Structural Behaviour and Deformation

Structural behaviour focuses on how a structure responds to loads, including how it deforms and distributes forces across its components. This understanding is vital for designing structures that remain stable and safe under various conditions. One common approach to analyzing structural behaviour is the displacement method, which considers how components shift or deform under load. However, many students find it difficult to conceptualize deformation on a system-wide scale.

One instructor highlighted this issue, stating, *"If they don't understand flexibility methods, they can't picture how an entire structure deforms because really flexibility method is like the simplest case."* - Participant C. This reveals that students often lack the ability to visualize how individual deformations contribute to the overall behaviour of a structure.

To improve understanding, instructors can use step-by-step examples, starting with simple cases of deformation and gradually increasing complexity. Visualization tools, such as augmented reality or animations showing deformations in real-time, can also help students see how structures respond to various loads.

Force Distribution

Force distribution examines how forces are spread across a structure, often represented graphically through influence lines. These diagrams show how internal forces or reactions change as loads move across a structure, making them essential for understanding dynamic conditions. Unfortunately, students frequently struggle to connect influence lines to internal force diagrams, as these concepts require a level of abstraction and mathematical reasoning that can be difficult for beginners.

As one faculty member observed, *"For students who are trying to learn influence lines, they struggle mightily. They're trying to extrapolate or parallel to internal force diagrams, and there's not [a relationship] in the way they're trying to see it."* - Participant D

Educators can help by integrating software tools that dynamically generate influence lines and connect them to practical examples, such as bridges with moving loads. Simplifying the introduction of these diagrams and demonstrating their real-world applications can make the concept more accessible.

Spatial Design and Constructability

Designing structures in three dimensions requires an understanding of spatial relationships and the ability to visualize stress distributions within a system. Constructability—the practical aspects of assembling a structure, such as tying rebar or pouring concrete—is equally important. However, many students lack hands-on experience, which limits their ability to grasp these concepts fully.

A faculty member explained, *"When students don't have a hands-on lab where they get to assemble, build formwork, and tie rebar cages, they don't understand constructability concerns and conflicts."* - Participant E. Without practical exposure, students struggle to see how theoretical knowledge applies in real-life construction scenarios.

Hands-on learning opportunities, such as lab activities or site visits, can provide students with the tactile experiences needed to understand spatial design and constructability. Incorporating model-building exercises or virtual reality tools can also help bridge this gap.

Advanced Structural Responses

Nonlinear behaviour, such as buckling or geometric nonlinearity, represents advanced structural responses where the relationship between loads and displacements is not proportional. These behaviours often occur under extreme conditions, such as high loads or unstable configurations. Understanding these phenomena requires a deep knowledge of stability and deformation, which many students find challenging.

One instructor remarked, *"For second-order effects or nonlinear behaviour, they need to visualize stability or buckling responses to make sense of the math."* - Participant E. This highlights the need for tools and strategies that make these abstract concepts more concrete.

Using simulations or case studies of real-world failures can help students visualize nonlinear responses. Breaking down complex equations into manageable steps and relating them to practical examples can also make these topics more approachable.

Load Scenarios and Design Considerations

Designing for various load scenarios—such as dead loads, live loads, and environmental loads like wind or earthquakes—is a critical skill in structural engineering. This involves combining different types of loads and applying specific factors to determine the most severe conditions a structure might face. However, many students struggle to manage these combinations, especially when deciding how to maximize or minimize certain factors.

One faculty member noted, *"Students struggle, getting outside of the formula itself. One of them, I'm trying to maximize. The other one, I'm trying to minimize. Do I make this 0? Do I make this 0.9?"* - Participant B. This confusion highlights the need for clear guidance on how to approach load combinations systematically.

To address these challenges, instructors can provide detailed examples of load combination scenarios, showing how to apply factors step by step. Relating these calculations to real-world design situations, such as the construction of high-rise buildings or bridges, can also help students see their practical relevance.

VI. Discussion

The findings of this study revealed seven key themes that reflect faculty members' perceptions of the challenges students face in understanding threshold concepts in structural engineering. These results align with prior research that identifies barriers to learning in engineering education, such as gaps in foundational knowledge [5], the need for interdisciplinary teaching approaches [3], and the role of innovative methods to support the mastery of threshold concepts [1].

One of the central findings is that students often struggle with abstract concepts such as internal forces and load paths. Faculty members noted that these concepts are challenging to visualize and apply, as they involve dynamic interactions that cannot be easily represented through traditional teaching methods, such as static diagrams. This is consistent with prior research suggesting that traditional approaches fail to convey the multi-dimensional nature of these ideas [3]. To address this, integrating innovative tools like augmented reality (AR) or 3D modeling could help students better understand these concepts. These tools allow students to see forces and load paths in a more interactive and realistic way, bridging the gap between theoretical knowledge and practical understanding.

A significant factor that emerged in the discussions was the importance of foundational knowledge. Faculty emphasized that students often enter structural engineering courses with weak foundations in subjects like mathematics, physics, and mechanics, which are essential for understanding advanced concepts. For example, gaps in calculus or mechanics prevent students from fully comprehending material behaviour under stress or the interaction of forces. These findings echo the findings of Knight [2], who argues that a strong foundation is critical for success in engineering education in general. Addressing this issue may involve implementing diagnostic assessments early in the course to identify gaps in knowledge and providing additional resources or remedial support to help students build the necessary skills.

Misconceptions about structural behaviour also present a significant barrier. Faculty observed that students often approach engineering problems with incorrect assumptions, such as believing that structures only experience static loads. These misconceptions hinder their ability to grasp the dynamic forces at play in real-world engineering problems. Research suggests that using reflective prompts and hands-on activities can help students recognize and correct these misunderstandings [5]. For instance, incorporating real-world case studies or problem-based learning exercises into the curriculum could help students better understand the complexity of structural behaviour.

A recurring theme in the findings is the lack of hands-on experience, particularly in areas like spatial design and constructability. Faculty noted that students often struggle to connect theoretical knowledge to practical applications because they lack opportunities to work on real-world problems. This aligns with Turkan [3], who argue that practical exercises, such as building physical models or engaging in lab-based activities, can enhance students' spatial reasoning and help them apply their learning in meaningful ways. Providing students with such opportunities could significantly improve their understanding of how theory translates into practice.

Another important finding relates to students' mindset and attitude toward threshold concepts. Faculty observed that students often approach these concepts with apprehension, influenced by the perceived difficulty of the topics. This negative mindset can affect their motivation and performance. Promoting a growth mindset through structured learning communities or peer mentoring programs could help address this issue. For instance, involving successful past students as learning assistants or mentors can create a supportive environment where current students feel encouraged to ask questions and seek help. This approach not only reinforces learning but also helps students build confidence in their abilities [1].

These findings highlight several opportunities for improving the teaching and learning of threshold concepts in structural engineering. Faculty can adopt asset-based approaches, which focus on leveraging students' existing strengths rather than emphasizing their weaknesses. For example, formative assessments could help identify areas where students excel, enabling instructors to design targeted interventions that build on those strengths. Collaborative learning opportunities and interdisciplinary teaching approaches could also help students make connections between different areas of knowledge, improving their overall comprehension.

In addition, integrating innovative teaching tools such as augmented reality, reflective prompts, and hands-on activities can help students better understand and apply threshold concepts. Addressing misconceptions and providing targeted support to students with weak foundational knowledge are also critical steps in improving their learning outcomes.

VII. Recommendations

The following recommendations are provided to statics instructors based on this research. Though additional research will be needed to determine the effectiveness of each recommendation, we recommend instructors consider the following as starting points for helping students overcome the threshold concepts identified in this work.

Use Visualization Tools: Instructors can enhance learning by using augmented reality (AR), 3D models, and simulations. Free resources like YouTube animations, SketchUp, and PhET simulations provide accessible alternatives. If AR or simulations are unavailable, pre-recorded demonstrations and visual guides can help.

Improve Prerequisite Skills: Many students struggle with math, physics, and mechanics, which affects their understanding of structural concepts. Instructors can use diagnostic quizzes at the start of the course to identify gaps. Providing online resources (Khan Academy, MIT OpenCourseWare), workshops, and peer mentoring can help students build a strong foundation.

Add Hands-On Activities: Simple, low-cost physical models like spaghetti bridges, foam beams, and LEGO structures can help demonstrate key concepts. Group problem-solving, site visits, and guest lectures provide practical exposure.

Focus on Clearing Misconceptions: Students often struggle with misconceptions about load paths, force distribution, and structural failure. Using think-pair-share discussions, real-time polling (Poll Everywhere), and case studies like the Tacoma Narrows Bridge collapse can help clarify misunderstandings. Reviewing common mistakes through guided exercises enhances conceptual learning.

Simplify Complex Ideas: Difficult concepts should be introduced step by step, starting with intuitive explanations before moving to calculations. Problem-solving templates, real-world examples (e.g., bridge load analysis, earthquake resilience), and structured guides can improve comprehension.

VIII. Implications and Future Directions

The findings of this study have several significant implications for structural engineering education and provide a foundation for future research. First, the identification of threshold concepts and their associated challenges can inform the development of targeted instructional strategies, including the integration of hands-on learning opportunities, enhanced visualization tools, and collaborative learning environments. Educators can use these insights to better align their teaching methods with students' needs, facilitating deeper understanding and application of critical concepts.

Curriculum developers can leverage these findings to design courses that address common misconceptions, ensuring students have a solid foundation before engaging with advanced topics. Additionally, academic administrators can prioritize faculty training programs that equip instructors with innovative teaching techniques, such as the use of augmented reality or interactive simulations, to overcome the abstract and complex nature of threshold concepts.

For future research, incorporating student perspectives is a crucial next step to gain a more comprehensive understanding of the learning barriers associated with threshold concepts. Mixed-methods studies combining qualitative and quantitative approaches could validate the findings and explore broader patterns across diverse institutions. Expanding the participant pool to include faculty and students from a variety of educational settings would also enhance the generalizability of the results.

Finally, longitudinal studies tracking students' progress and mastery of threshold concepts over time could provide valuable insights into the long-term effectiveness of educational interventions. By addressing these future directions, the field of structural engineering education can continue to evolve, ensuring students are well-prepared to meet the demands of professional practice.

IX. Limitations

This study is subject to several limitations. First, the research focuses exclusively on faculty perspectives from R1 institutions in the USA, which may limit the generalizability of the findings to other institutional contexts or countries. Second, the qualitative nature of the study relies on semi-structured interviews, which are inherently subjective and may reflect individual biases of the participants. However, the qualitative approach for this study was deliberately chosen to allow for deeper insights into the nuanced experiences and perspectives of faculty regarding threshold concepts. Third, the research does not include direct input from students, which could provide valuable insights into their firsthand challenges with threshold concepts.

X. Conclusion

This study explored the challenges faculty members perceive students face in understanding threshold concepts in structural engineering through qualitative interviews. Seven key themes emerged, capturing the barriers students encounter, such as gaps in foundational knowledge, misconceptions, and difficulties with abstract concepts like internal forces and load paths. We propose that educators consider new approaches by integrating interventions such as hands-on activities and innovative visualization tools to support students' learning journeys. The findings and recommendations from this study have the potential to enhance students' mastery of threshold concepts, improve their overall academic performance, and better prepare them for the technical and practical demands of the engineering profession.

References

[1] J. H. F. Meyer, D. Knight, D. Callaghan, and T. Baldock, "An empirical exploration of metacognitive assessment activities in a third-year civil engineering hydraulics course," *European Journal of Engineering Education*, vol. 40, no. 3, pp. 309-327, 2015.

[2] D. Knight, D. Callaghan, T. Baldock, and J. H. F. Meyer, "Identifying threshold concepts: Case study of an open catchment hydraulics course," *European Journal of Engineering Education*, vol. 39, no. 2, pp. 125-142, 2014.

[3] Y. Turkan, R. Radkowski, A. Karabulut-Ilgu, A. Behzadan, and A. Chen, "Mobile augmented reality for teaching structural analysis," *Advanced Engineering Informatics*, vol. 34, pp. 90-100, 2017.

[4] A. Harlow, J. Scott, M. Peter, and B. Cowie, "'Getting stuck' in analogue electronics: Threshold concepts as an explanatory model," *European Journal of Engineering Education*, vol. 36, no. 5, pp. 435-447, 2011.

[5] D. Cernusca and G. Bham, "Application of threshold concepts to improve a design-focused course in transportation engineering," *Transportation Research Record*, vol. 2211, pp. 10-17, 2011.
[6] J. H. F. Meyer and R. Land, "Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines," in *ISL10 Improving Student Learning: Theory and Practice Ten Years On*, Oxford, UK, 2003, pp. 412-424.
[7] V. Braun and V. Clarke, *Thematic Analysis*. SAGE Publications, 2021. Accessed: Jan. 02, 2025. [Online]. Available: https://us.sagepub.com/en-us/nam/thematic-analysis/book248481