Work In Progress: Evaluating the Cultural Context of Engineering and Engineering-Related Concept Inventory Assessment Items

Shauna N. Adams, Purdue University, West Lafayette

Shauna is currently a PhD student in Engineering Education at Purdue University. She previously worked for 10 years as a Systems Surety Engineer and 15 years as a coordinator/advisor of various pre-college engineering programs. Shauna earned her BS in Mechanical Engineering from North Carolina Agricultural and Technical State University and her MS in Mechanical Engineering from The Ohio State University. Her research interest includes understanding the impact of community-based engineering programs on student major choice for underrepresented groups in engineering, with a specific focus on Black/African American youth and inclusive program evaluation methods. Shauna is engaged in Purdue's Engineering Education Graduate Student Association and Black Graduate Student Association.

Dr. Kerrie A. Douglas, Purdue University, West Lafayette

Dr. Douglas is an Associate Professor in the Purdue School of Engineering Education. Her research is focused on improving methods of assessment in engineering learning environments and supporting engineering students.

Philip Goldberg, Purdue University, West Lafayette

Philip Goldberg is a First Year Engineering undergraduate student at Purdue University looking to pursue a degree in mechanical engineering. He is a part of the First Time Researcher program at Purdue, currently completing research in the School of Engineering Education and Science and Ethics of Educational Data lab under Dr. Kerrie Douglas.

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There is very little understood about how the context of engineering assessment questions can serve to unnecessarily confuse, distract, or indirectly communicate who belongs (and who does not) in engineering classrooms. Globally concept inventories are used to assess students' conceptual understanding of specific subject areas and study the effectiveness of curriculum efforts targeted toward increasing students' conceptual understanding of different topics using real word contexts. Using content analysis, researchers reviewed three concept inventories and the sociocultural norms and lived experiences of the represented contexts, which have implications for fairness. The team analyzed and identified the context of over 90 concept inventory questions and created four major categories of questions where different groups of participants may react to the context differently or have difficulty answering the question. The categories were *access to technology*, *culturally sensitive*, *insider knowledge*, and *assumed experiences*. The context of the question can be essential to answering the question so a lack of understanding of the context could prevent students from accurately answering the question, or the context of the question is not essential to answering the question, but the context can be a distraction. Engineering undergraduate students consist of several racial, ethnic, and cultural groups made up of both domestic and international students. This research team seeks to encourage concept inventory authors to assess the context of the proposed concept inventory items for sociocultural and racial/ethnic awareness.

Introduction

There is very little understood about how the context of engineering assessment questions can serve to unnecessarily confuse, distract, or indirectly communicate who belongs (and who does not) in engineering classrooms. Simply put – it is unknown how engineering assessment contexts can be biased against groups of students, particularly those students who are most vulnerable to discrimination based on their minority group status in comparison to the instructors or other students in the class. Considering the role assessments play in educational decisions and research, it is important to understand the extent to which current assessments are written to fairly assess diverse groups of students in engineering classrooms. In the development stage, engineering education researchers often conduct a series of validity tests to determine how well the assessment questions measure the constructs as intended by the authors. However, the majority of validation studies in engineering education do not look at how items function for subgroups of learners, particularly different racial, ethnic, and cultural groups [1]. Even frameworks designed to improve the validity evidence provided regarding an assessment's score, still leave out evaluations of fairness [2]–[4]. To gain a better understanding of how well engineering assessment contexts are reflective of the diverse experiences of engineering students in the U.S., this work-in-progress paper explores the contexts of concept inventories from a sociocultural perspective.

The purpose of this WIP paper is to identify contexts that are used in three concept inventories and to understand what sociocultural norms and lived experiences are represented in those contexts, which have implications for fairness. The overarching research question is: *What sociocultural norms and lived experiences are dominant in the context of concept inventory questions?*

Literature Review

Concept Inventories

Science, technology, engineering, and mathematics (STEM) educators and educational researchers commonly use concept inventories (CIs) to assess students' conceptual understanding of foundational topics by asking students about the topics in everyday, out of the classroom contexts [2], [5]. Globally CIs are used to assess students' conceptual understanding of specific subject areas and study the effectiveness of curriculum efforts targeted towards increasing students conceptual understanding of a topic (e.g., physics, statics, chemistry) [6]. While multiple-choice tests in the forms of mid-terms and finals are commonly used in many STEM classes researchers have found some students can pass course exams and still lack the fundamental disciplinary insights that make up the course [2], [7], [8]. Concept inventories are specifically developed to assess a student's conceptual understanding of fundamental constructs and understandings of specific academic topics while introducing distractors that can indicate partial or incorrect topical understandings or misconceptions if answered incorrectly [9].

CIs have played a major role in engineering education research with more than $40 million in NSF engineering education research projects (https://www.nsf.gov/awardsearch/). CIs have been developed and deployed in engineering education environments using various validation methods [2], [3], [7], [10]. These methods however do not mention efforts to look at question context when developing the concept inventories. In addition, because CI developers write the questions specifically to assess students' conceptual understanding of the topic in a 'real-world' context, there is potential that not all students would have the same exposure or relatability to the context [11]–[13]. Thus, the questions have the potential to perpetuate contextual bias through sociocultural norms[11], [12], [14]. National organizations that establish assessment standards acknowledge differences in mean scores by racial and ethnic subgroups. However, little research has been done to examine assessment fairness from the sociocultural perspective and the influence question context may have on student outcomes.

Assessment Fairness and Sociocultural Context

Sociocultural context is an important aspect of fairness of assessment because it impacts learner experiences taking the test. When assessment fairness is overlooked in different aspects of assessment creation there is potential for bias or insensitivities to impact different groups. Assessment fairness as defined by *Standards* addresses three main areas: the consistency of the test construct and score interpretation across all users, the ability not to advantage or disadvantage users with characteristics irrelevant to the test construct, and the reduction of barriers through consideration of characteristics of the test population from test development through scoring and interpretation [14]. Sociocultural centering is the emphasis on social interactions and cultural practices on knowledge development [15]. Assessment fairness from a sociocultural perspective leans into the second and third areas of fairness to broaden the thinking of fairness to consider sociocultural implications and the advantages or disadvantages these implications may have on different groups of people as it pertains to equitable testing experiences [14]–[17]. For this paper sociocultural context is the set of circumstances influenced by a group's understanding of specific cultural, religious, environmental, occupational, social, and geographic habits, traditions, and beliefs in which a concept is framed.

Context in Assessment Items

Context and language evaluation involves interrogating the elements of a test item for word choice and subject sensitivities [18]. Context sensitivity is the review of context in assessment items to see if there is knowledge other than what is being assessed that may cause one group over another to answer the question a certain way [12], taking care to review items that can be confusing, misleading, or morally or culturally problematic [11]. In her assessment fairness framework, Arbuthnot also calls this contextual item bias[11]. To examine Huffman and Heller's conclusions that experiences with context can affect the understanding of concepts, Stewart, Griffin, and Stewart looked at context sensitivity using different transformations on the Force Concept Inventory (FCI). One of the transformations is *change to the physical system*. This involved "changing a concrete physical system with another concrete system" (e.g. "truck" to "bowling ball" as mentioned in the paper) [19], [20]. When the physical system was changed with another system, there was a positive 4.17% shift in average scores among participants [19]. Similarly, in a study with South African students, researchers found that changing the context of the questions in a physical science assessment changed the frequency of correct answers among the students depending on their cultural backgrounds [13]. In another study, McCullough looked at the gendered context in the FCI. All the stereotypically male context was changed to context stereotypically associated with females in the Revised FCI (RFCI). Results show there was no change in average scores among female participants, but there was a negative change in average scores for male participants. Results implied that context can impact assessment performance, especially when the context is situated outside the culturally normed context of the group [21]. Culturally insensitive context can also be a distraction to participants. McCullough also recalls an example from a colleague who was administering a concept inventory in Thailand. The participants became distracted because one of the questions referenced placing feet on someone else, and culturally, that is unacceptable and unclean [21].

Methods

The first phase of this research project will include identifying the context of questions within different engineering-related concept inventories. The focus will not be on any one concept inventory because the purpose is to get a general understanding of contextual themes across engineering-related CIs. The second phase of the research project will include interrogating the themes and identifying groups the sociocultural norms may be associated with.

Concept Inventories Reviewed

The presented work is part of a larger study which is examining nine concept inventories published and available for instructor use on the AIChE Concept Warehouse (https://conceptwarehouse.tufts.edu/cw/CW.php). For this WIP, we have begun analyzing three concept inventories, shown in Table 1. The AIChE Concept Warehouse is a web-based tool used by faculty to access over 10 engineering-related concept inventories [22].

Table 1 *Concept Inventories*

Concept Inventory	Item No.	Notes
Dynamics Concept Inventory (DCI) [23]	29	The DCI is designed to identify the understanding of 11 concepts
Statistics Concept Inventory (SCI) [24]	25	The SCI is designed to identify understanding in 19 main concept areas. A shortened version of the concept inventory is available on the AIChE Concept Warehouse.
Heat and Energy Concept Inventory (HECI) [25]	36	The HECI is designed to identify understanding in four main concept areas

Design

To answer the overarching research question: *What sociocultural norms and lived experiences are dominant in the context of concept inventory questions*, the team used content analysis and reviewed each CI question guided by answering the following questions:

1. What is the general context of the question?
2. What group/community may have familiarity with this topic?
3. Was the language used in the concept inventory question accessible?
4. Were there any graphics associated with the concept inventory question?
5. What other observations are notable?

Researchers individually reviewed and documented the content of the assessment questions according to the guided questions. Individual responses to the concept inventory questions were only shared after each researcher completed their evaluation of the CI questions. This was done so that researchers' responses remained objective. There was also space to explain a response or additional comments. In lieu of showing the exact form filled out by the researchers Figure 1 is an example of the form that the research team filled out with excerpts from each of the concept inventories reviewed. The first column identified the concept inventory being reviewed. The second column identified the inventory question number. In the third column through the seventh column addressed the guided questions from above. For Figure 1 the *Other Notes* column has been modified to contain the actual comments from all three researchers for the specific excerpts chosen. For the actual form each researchers' observations were on a separate form.

Originally there were two questions about the type of question and question type, but since all the questions were multiple choice and centered around understanding fundamental concepts of a subject and not application the initial responses were repetitive, so the team chose to remove those questions.

After reviewing the concept inventories the review team combined their observations and discussed their responses with each other.

Figure 1 *Example of Observation Form*

Observer						
CI	Question #	Context	Experience	Accessible language	Graphic	Other notes
XXX	X	Students on rolling chairs pushing off each other in opposite directions	Knowledge of rolling chairs, acceptance of physical contact between students, male students only	No "Office chairs" have wheels but the question doesn't explain that	Yes	Setup of the problem is unusual and possibly distracting Both students in the image are male. Student A is not actually barefoot as said in the question and the office chairs do not appear identical The graphic is incorrect they are supposed to be in identical chairs. This could be a better question overall.
XXX	XX	Number of boys born in rural and urban hospitals	Hospitals, children born, boys gender, rural and urban settings	No "Rural" and "urban" not defined; "small" and "large"	No	Implicitly references gender distribution in a population You have to know what the difference is between urban and rural to be able to answer this question Rural can have differing definitions depending on where somebody is from
XXX	XXX	sparks from a grinding machine, 4th of July sparkler and a fireplace poker, burning skin	machining, festivals using sparklers, building a wood-burning fire in a fireplace	no	no	They reference a wheel grinder or sparklers to provide reference but they are still very specific and everyone may not know what a fireplace poker looks like. Without a reference it is hard to answer this question Burn context could be distressing; Culture-specific holiday; Could have said "metal sparks" and "metal rod" to simplify context An international student has a good chance of not knowing what the 4th of July is. A lot of people will also not know what a fireplace poker or grinding wheel are.

Review Team

The original review team consists of two graduate researchers and one undergraduate researcher. One graduate researcher identifies as a US born black female from a middle to lower middle class coastal suburban background. She has degrees in engineering and worked in systems engineering and product design and production for several years. She has a familiarity with the topics of the concept inventories reviewed. One graduate researcher has a background in educational psychology and engineering with limited familiarity with the concept inventory

topics evaluated. The undergraduate researcher is a white male first-year engineering student with limited familiarity in the concept inventory topics evaluated. He comes from a middle-class suburban upbringing and has been exposed to engineering through entry level courses and family occupations. The team, with various levels of exposure to the subject areas evaluated and different backgrounds, provides a diversity of perspectives when evaluating the concept inventory questions.

Results

Though still a work in progress, the research team has completed the initial review of the concept inventories. The team reviewed over 90 concept inventory questions between three concept inventories and identified the context of each question using a series of free-response questions on a data form. The researchers all identified the same general context for each question where one existed. There were a variety of topics including turning Ferris wheels, crashing vehicles, quiz scores, and steam in a turbine to name a few. To summarize most of the topics involved academics, geographic relevance, temperature, the use of kitchen items, vehicle functions, mechanical systems, laboratory setups or experimentation, food or beverage items, sports or entertainment, balls and boxes in motion or suspended, manufacturing, and actions of people. Seven questions did not contain cultural context. For most of the questions, the team comments and observations were similar or identified the same discrepancies in the accessible language and other comments sections.

The team identified four major themes of questions where different groups of participants may react to the context differently or have difficulty answering the question. We have categorized these themes as access to technology, culturally sensitive, insider knowledge, and assumed experiences.

Access to technology includes inventory questions where knowledge of how technology works is needed to answer the question. These questions normally mentioned the use of some technology with little to no explanation of its function. Examples include the mention of a laptop, heat exchanger, grinding wheel, fire poker, freezer, and boomerang.

Culturally sensitive questions were inventory questions where the context could become a distraction because it is either offensive, controversial, or morally questionable within some cultures. Examples include burning skin with hot objects, placing your tongue on a freezing pole, pushing off someone with your bare feet, and dieting.

*Insider knowledge i*nventory questions contain context that could be interpreted differently by different cultural groups. Often time to answer these questions require a specific use definition. Examples include referencing temperature without specifying Fahrenheit or Celsius, referencing rural and urban, referencing GPA and letter grades, referencing dice without specifying 6-sided dice, and using a brand name to describe a material (e.g., Styrofoam).

Assumed experiences inventory questions context contains lived experiences that are more commonly experienced by specific groups. Examples include referencing activities and items like the 4th of July, Ferris wheels, swimming, snow, crushed ice, ceramic tile, carpeted floor, rubbing alcohol, metal ice tray, and Consumer Reports.

Table 2 provides a summary of how many CI questions were categorized under each theme. It was possible for a question to have more than one theme assigned to it.

Table 2 *Summary of Themed Responses from CI Questions*

Topic	Culturally Sensitive	Access to Technology	Insider Knowledge	Assumed Experiences
Questions	4/90	14/90	16/90	24/90
Percent	4.44	15.56	17.78	26.67

Discussion and Implications

This work-in-progress paper started the first phase of our research by identifying the sociocultural topics in engineering-related concept inventory questions. The team was able to identify the context for 83 of the 90 questions. This aligns with the theme of many concept inventories where most of them attempt to present conceptual questions within the backdrop of real-world experiences and environments. This is evident in the inventories assessed using topics like weather temperature changes, walking barefoot across surfaces, cooking pizza, and rockets in space. However, these topics may have different levels of relevance depending on the test taker.

There are two ways in which the context of the question can negatively impact the test taker. The context of the question can be essential to answering the question so a lack of understanding of the context could prevent you from accurately answering the question, or the context of the question is not essential to answering the question, but the context used is a distraction. These align with areas two and three of the *Standards* fairness definition [14]. An example of the context being essential to answer the question is a question about the percentage of boys born at a small rural hospital vs a large urban hospital. Knowledge of what urban and rural mean in reference to overall quantity is needed to accurately answer the question. An example where the context is not essential but could be a distraction is a question about students licking a very cold ice scraper vs licking a wooden ice scraper. The idea of someone licking an ice scraper may be a distraction, but the context could change without affecting the concept being assessed. The possible distractors mentioned are not the same as conceptual distractors purposefully placed within the questions and answers to evaluate conceptual understanding [9]. Both of these impacts are incorporated into the four themes of access to technology, culturally sensitive, insider knowledge, and assumed experiences concept inventory questions.

The four themes identified highlight areas of sociocultural context sensitivity. Arbuthnot specifically mentions reviewing items that can be confusing, misleading, or morally or culturally problematic [11]. With access to technology, though participants may have familiarity with the function of a freezer, without explanation familiarity with a grinding wheel may not be as common. Culturally sensitive contexts like being burned and dieting can be triggering to groups who may have experienced trauma in these areas, and as mentioned in [21] the reference to bare feet on others can offend different cultural or religious groups. These topics overall could be distractors preventing groups from focusing on the concept being assessed. For insider knowledge, depending on the participant the test question could be a distraction if the familiarity they have with the term does not align with the context being described. With assumed experiences having a familiarity with context items or events could be helpful when answering the questions.

As we continue to assess remaining concept inventories, we plan to expand on our knowledge of the groups most represented in these questions. At the conclusion of this

assessment, we will have categorized almost 200 inventory questions. Engineering undergraduate students consist of several racial, ethnic, and cultural groups made up of both domestic and international students. These students are from a range of socioeconomic and geographic backgrounds. Within these students, there are a variety of experiences that they share and others that may be more prevalent in some groups than in others.

Conclusion and Future Work

Teaching and assessing engineering students' conceptual understanding is an important challenge for both instructors and researchers. However, in doing so, it is imperative that the diversity of students' lived experiences are reflected in both the curriculum and assessment. In this WIP paper, we have found that many of the questions include terms and contexts that could be either interpreted differently than the authors intended or unfamiliar to some students. While our study is focused on concept inventories, assessments are used in engineering classrooms every day. The themes found in our study could be simply summed as representing the experiences of White, middle class, Midwestern U.S. students. Future research should consider the extent to which other assessments predominantly reflect one single group's experiences. To create more fair experiences for students, researchers and instructors should review the questions to consider what terms and contexts are understood or experienced culturally. While unfair assessment questions likely do not account for all of the discrepancies in scores between racial and ethnic groups, future research should consider how more inclusive questions improves test scores for different groups of students. Concept inventories have been a valuable tool in engineering education, helping to further educational reform. Yet, without intentionally decentering White experiences, they can further perpetuate achievement differences between groups of students.

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References

[1] K. A. Douglas, A. Rynearson, S. Purzer, and J. Strobel, "Reliability, validity, and fairness: a content analysis of assessment development publications in major engineering education journals," *The International journal of engineering education*, vol. 32, no. 5, pp. 1960–1971, 2016.

[2] N. Jorion, B. D. Gane, K. James, L. Schroeder, L. V. DiBello, and J. W. Pellegrino, "An analytic framework for evaluating the validity of concept inventory claims," *J. Eng. Educ.*, vol. 104, no. 4, pp. 454–496, Oct. 2015, doi: 10.1002/jee.20104.

[3] J. W. Pellegrino, L. V. DiBello, K. James, N. Jorion, and L. Schroeder, "Concept inventories as aids for instruction: a validity framework with examples of application," p. 7, 2011.

[4] G. O. Boateng, T. B. Neilands, E. A. Frongillo, H. R. Melgar-Quiñonez, and S. L. Young, "Best practices for developing and validating scales for health, social, and behavioral research: a primer," *Frontiers in Public Health*, vol. 6, no. 149, pp. 1–18, Jun. 2018, doi: 10.3389/fpubh.2018.00149.

[5] A. Madsen, S. B. McKagan, and E. C. Sayre, "Best practices for administering concept inventories," *The Physics Teacher*, vol. 55, no. 9, pp. 530–536, Dec. 2017, doi: 10.1119/1.5011826.

[6] R. E. Furrow and J. L. Hsu, "Concept inventories as a resource for teaching evolution," *Evolution: Education and Outreach*, vol. 12, no. 1, p. 2, Jan. 2019, doi: 10.1186/s12052-018-0092-8.

[7] R. L. Miller, R. A. Streveler, D. Yang, and A. I. S. Román, "Identifying and repairing student misconceptions in thermal and transport science: concept inventories and schema training studies," *Chemical Engineering Education*, vol. 45, no. 3, Art. no. 3, Jul. 2011.

[8] D. Sands, M. Parker, H. Hedgeland, S. Jordan, and R. Galloway, "Using concept inventories to measure understanding," *Higher Education Pedagogies*, vol. 3, no. 1, pp. 173–182, Jan. 2018, doi: 10.1080/23752696.2018.1433546.

[9] T. Reed-Rhoads and P. K. Imbrie, "Concept inventories in engineering education," presented at the National Research Council's Workshop Linking Evidence to Promising Practices in STEM Undergraduate Education, Washington, DC, 2008.

[10] N. A. Stites, K. A. Douglas, D. Evenhouse, E. Berger, J. Deboer, and J. F. Rhoads, "A validation and differential item functioning (DIF) study of an abbreviated dynamics concept inventory," *International Journal of Engineering Education*, vol. 35, no. 2, pp. 491–509, 2019.

[11] K. Arbuthnot, *Global perspectives on educational testing: examining fairness, high-stakes and policy reform*. Bingley, United Kingdom: Emerald Publishing Limited, 2017. Accessed: Feb. 13, 2022. [Online]. Available: http://ebookcentral.proquest.com/lib/purdue/detail.action?docID=4717077

[12] P. J. Keegan, G. T. L. Brown, and J. A. C. Hattie, "A psychometric view of sociocultural factors in test validity: the development of standardized test materials for māori-medium schools in new zealand/aotearoa," in *Constructing Educational Achievement*, Routledge, 2013.

[13] L. G. Enderstein and P. E. Spargo, "The effect of context, culture and learning on the selection of alternative options in similar situations by South African pupils," *International Journal of Science Education*, vol. 20, no. 6, pp. 711–736, Jul. 1998, doi: 10.1080/0950069980200608.

[14] American Educational Research Association, *Standards for educational and psychological testing*. Washington, DC: American Educational Research Association, 2014.
[15] C. Gipps, "Chapter 10: socio-cultural aspects of assessment," *Review of Research in Education*, vol. 24, no. 1, pp. 355–392, Jan. 1999, doi: 10.3102/0091732X024001355.
[16] G. Stobart, "Fairness in multicultural assessment systems," *Assessment in Education: Principles, Policy & Practice*, vol. 12, no. 3, pp. 275–287, Jan. 2005, doi: 10.1080/09695940500337249.
[17] C. Gipps and G. Stobart, "Fairness in assessment," in *Educational assessment in the 21st century: Connecting theory and practice*, C. Wyatt-Smith and J. J. Cumming, Eds. Dordrecht: Springer Netherlands, 2009, pp. 105–118. doi: 10.1007/978-1-4020-9964-9_6.
[18] R. Hambleton and J. Rogers, "Item bias review," *Practical Assessment, Research, and Evaluation*, vol. 4, no. 6, pp. 1–3, 1994, doi: https://doi.org/10.7275/jymp-md73.
[19] J. Stewart, H. Griffin, and G. Stewart, "Context sensitivity in the force concept inventory," *Physical Review Special Topics. Physics Education Research*, vol. 3, no. 1, Jun. 2007, doi: 10.1103/PhysRevSTPER.3.010102.
[20] D. Huffman and P. Heller, "What does the Force Concept Inventory actually measure?," *The Physics Teacher*, vol. 33, no. 3, pp. 138–143, Mar. 1995, doi: 10.1119/1.2344171.
[21] L. McCullough, "Gender, context, and physics assessment," *Journal of International Women's Studies*, vol. 5, no. 4, pp. 20–20, May 2004.
[22] M. D. Koretsky *et al.*, "The AIChe 'Concept Warehouse': a web-based tool to promote concept-based instruction," *Advances in Engineering Education*, vol. 4, no. 1, 2014, Accessed: Feb. 13, 2023. [Online]. Available: https://eric.ed.gov/?id=EJ1076138
[23] G. Gray, F. Costanzo, D. Evans, P. Cornwell, B. Self, and J. Lane, "The dynamics concept inventory assessment test: a progress report and some results," presented at the 2005 Annual Conference, Jun. 2005, p. 10.1278.1-10.1278.16. Accessed: Jul. 13, 2022. [Online]. Available: https://peer.asee.org/the-dynamics-concept-inventory-assessment-test-a-progress-report-and-some-results
[24] A. Stone, K. Allen, T. R. Rhoads, T. J. Murphy, R. L. Shehab, and C. Saha, "The Statistics Concept Inventory: a pilot study," in *33rd Annual Frontiers in Education, 2003. FIE 2003.*, Nov. 2003, vol. 1, pp. T3D-1. doi: 10.1109/FIE.2003.1263336.
[25] M. Prince, M. Vigeant, and K. Nottis, "Development of the Heat and Energy Concept Inventory: preliminary results on the prevalence and persistence of engineering students' misconceptions," *Journal of Engineering Education*, vol. 101, no. 3, pp. 412–438, 2012, doi: 10.1002/j.2168-9830.2012.tb00056.x.