Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #46085

Systematic literature review on the common misconceptions in thermodynamics, fluid mechanics, and heat transfer

Dr. Adrian Rodriguez, zyBooks, A Wiley Brand

Adrian Rodriguez is a Senior Engineering Content Developer for zyBooks, a Wiley brand and a Lecturer in Mechanical Engineering at The University of Texas at Austin. His research interests include engineering education, multibody dynamics, contact and impact with friction, electro-mechanical systems, and nonlinear dynamics. He earned his B.S. degree in Mechanical Engineering from The University of Texas at Austin and his M.S. and Ph.D. degrees in Mechanical Engineering from The University of Texas at Arlington.

Ms. Linda Ratts, Wiley
Lauren Fogg, zyBooks, a Wiley Brand

Lauren Fogg is an Engineering Content Developer at zyBooks, a Wiley Brand. She has a Bachelor's degree in Mechanical Engineering and a Master's degree in Mechanical Engineering. She also has a PhD in Engineering, concentration: Engineering Education. Her research interests are diversity, gender equity, retention, project-based learning, and cognitive models of problem-solving.

Yasaman Adibi, zyBooks

Yasaman Adibi is an Engineering Content Author at zyBooks. She earned her PhD in Electrical Engineering from the University of Minnesota in 2015, where her research focused on medical imaging using ultrasound. She also did two years of postdoctoral resear

Dr. Ryan Barlow, zyBooks, A Wiley Brand

Ryan Barlow obtained his Bachelor's Degree in Mechanical Engineering from the University of Utah in 2012, his Master's Degree in Science Education from the University of Maryland in 2016 and his PhD in Engineering Education from Utah State University in 2020. He currently works for zyBooks, A Wiley Brand creating interactive content for online mechanical engineering textbooks. His current research focuses on online engineering assessment, accessibility in online textbooks, and studying the effectiveness of online textbooks in engineering courses.

Ms. Jenny Welter, Wiley

Jennifer "Jenny" Welter has been a publishing professional for more than two decades, specifically focused on engineering publications and courseware during the majority of her tenure. She is passionate about supporting engineering education, specifically focused on content and assessment development for more effective student learning. She earned her BA in English from The University of Iowa.

James Eakins, zyBooks, A Wiley Brand

Systematic literature review on the common misconceptions in thermodynamics, fluid mechanics, and heat transfer

Abstract

Student misconceptions are rooted in their experiences from everyday life and unsteady foundations from previous courses. These misconceptions often have a negative impact on students' conceptual understanding within an engineering subject. The literature includes many articles that identify misconceptions in engineering thermodynamics, fluid mechanics, and heat transfer, and some offer strategies for addressing these misconceptions. However, a recent literature review on the misconceptions that have persisted in these engineering subjects was not found. A systematic literature review on common misconceptions in engineering thermodynamics, fluid mechanics, and heat transfer was conducted for this paper. In total, 32 articles were found within mechanical engineering and engineering education research from the past 20 years that focused on the search criteria for misconceptions in thermodynamics, fluid mechanics, and heat transfer. The search terms used to find articles included: student misconceptions, mistakes, errors, and misunderstandings. The most common misconceptions in thermodynamics were: differentiation among heat, energy, and temperature, entropy, and steady-state vs. equilibrium processes. In fluid mechanics, the common misconceptions included: Bernoulli's principle, gravitational effects, and fluid statics. The common misconceptions in heat transfer included: differentiation among heat, energy, and temperature, rate vs. amount of transfer, and modes of heat transfer (conduction, convection, radiation). A distinction is made in this literature review between primary and secondary misconceptions, where the secondary misconceptions typically arise from a lack of addressing primary misconceptions. The methods that instructors and researchers used to identify misconceptions were collected and categorized based on assessment type. Similarly, the strategies developed to repair and prevent student misconceptions are presented. With this literature review, a more cohesive view of student misconceptions can be formed, so that instructors may anticipate these misconceptions in their own courses and attempt to remediate them, as well as facilitating a deeper understanding of student misconceptions that may be more generalized to engineering education as a whole.

Introduction

Misconceptions are incorrect or incomplete understandings of concepts sometimes due to the overgeneralization of ideas [1]-[3]. These misconceptions can originate from various sources, such as prior knowledge, personal experiences, teaching methods, textbooks or educational materials, and cultural differences. Students who enter a class with knowledge based on their previous experiences or education, or preconceptions, can overcome their misconceptions by standard instruction [4]. For example, a student might think that temperature determines how "cool" or "warm" a body feels, a common misconception rooted in everyday observations rather than scientific principles [5]. In other cases, the way information is presented can lead to misunderstandings. If a professor oversimplifies a concept or uses ambiguous language, students can develop incorrect interpretations or connections between concepts. Meltzer [6] found that the majority of students that drew a P-V diagram interpreted it incorrectly when trying to solve problems related to the work done for a process. Other misconceptions are resistant to change and cannot easily be repaired or corrected using traditional instruction, unlike preconceptions [4]. These types of misconceptions are often referred to as robust misconceptions since they persist in core engineering concepts and require a conceptual change model to address them [1][7].

A large body of research exists in the area of repairing and/or preventing student misconceptions in engineering thermodynamics, fluid mechanics, and heat transfer [1][5][8]-[11]. But educators must first identify the misconceptions in their specific courses. A diagnostic assessment, such as a concept inventory, can help an instructor identify students' misconceptions early in a course so as to address them before being ingrained in a student's memory. Many concept inventories have been developed and improved upon over time, specifically for thermodynamics, fluid mechanics, and heat transfer [12]-[16]. With the help of these assessment tools, educators can gain the necessary understanding about student background understanding and inform how they can begin to repair and/or prevent student misconceptions. Some interventions include matrix exercises allowing a learner to see the connection between ideas [17]-[18], active learning strategies, like peer instruction, classroom communication systems and team teaching [19], problem-based learning which uses inquiry to ask students open-ended questions [20], computer-based modules comprising interactive questions, animations, and videos [21]-[22], and visually-oriented engineering scenarios [23]. By understanding the origins and types of misconceptions and their impact on learning, educators can better support students in developing accurate and robust understandings of engineering concepts.

The focus of this systematic literature review was limited to engineering thermodynamics, fluid mechanics, and heat transfer. The most common misconceptions from each subject area were collected and organized into the top 3 most common misconceptions that are considered primary misconceptions (or robust misconceptions). The paper also details the secondary misconceptions that arise from these primary misconceptions. The methodology used in the present work was informed by systematic literature reviews conducted in other engineering education subjects [24]-[26]. The following high-quality search databases were used, including some open-source search engines: Education Resources Information Center (ERIC), Ei Compendex, Wiley Online Library, ASEE PEER, and Google Scholar. The key search terms used included, but were not limited to: student misconceptions, alternative conceptions, mistakes, errors, misunderstandings, thermodynamics, fluid mechanics, heat transfer, and thermal science. In addition, forward and backward referencing techniques were employed to comprehensively review the related literature. A total of 32 articles were found within engineering education research that met these criteria from the past 20 years. These articles either focused on identifying misconceptions or repairing and preventing misconceptions within engineering thermodynamics, fluid mechanics, and heat transfer. Seven articles are discussed in this review that focus on developing concept inventories, a useful tool among educators to identify common misconceptions among their students and assess changes in student understanding over time. Some articles found during our search focused specifically on misconceptions experienced in chemical engineering fluid mechanics, thermodynamics, and heat transfer courses. Since the focus of chemical engineering courses differs from mechanical engineering courses, those articles were excluded from this literature review in order to focus on misconceptions in mechanical engineering courses.

Student misconceptions in thermodynamics

Concept inventories (CI) are a vital assessment tool that educators can use as a pre-test to determine the initial knowledge state of students, and where robust misconceptions and gaps in students' understanding of important concepts exist. When used in conjunction with a post-test, educators can assess changes in student performance and understanding resulting from a course experience or other intervention. The application of concept inventories in STEM began with the development of the Force Concept Inventory (FCI), which was used by physics professors to measure student understanding of important concepts, and the results of which were the impetus for significant innovation in physics instruction [27]. Using FCI as a model, Midkiff et al. [12] developed two Thermodynamics Concept Inventories (TCIs) that were intended to be used in a two-course thermodynamics sequence. Streveler et al. [28] developed the Thermal and Transport Concept Inventory (TTCI) that identified concepts of high importance and low student understanding in the thermal and transport sciences, which includes thermodynamics [28]-[30]. Over the past 20 years, these three CIs and others [13] have been used to identify the most common student misconceptions in engineering thermodynamics. This literature review found that the top 3 primary misconceptions in thermodynamics are:

1. Differentiation among heat, energy, and temperature [5][30]-[35].
2. Misunderstandings related to entropy and its implications with the 2nd law of thermodynamics [4][8][28][32][36]-[37].
3. Confusion between steady-state and equilibrium processes [8][30][35][37].

In terms of primary misconception #1, Saricayir et al. [31] specifically states that heat and temperature during a change of state are not understood well by students. Self et al. [5] and Foroushani [32] note that students often think that heat and temperature are equivalent, concluding that the temperature of a system must always rise due to input heat transfer. Students incorrectly interpret heat vs. temperature examples in their environment, while failing to understand the connections to deeper concepts, like the role of flow work or the relationship to mass and specific heat [32]. Similarly, students don't always understand the differences between temperature and energy, such as internal energy, and often think of them as being equivalent

[7][30][34]. The following secondary misconceptions found in the literature are likely the result of primary misconception #1. For example, Foroushani [32] found that the heat vs. temperature misconception led to student misunderstandings between adiabatic and isothermal processes, as well as phase-change processes. Student misinterpretations about work as a form of energy resulted in confusion when applying the first law of thermodynamics [38].

Poor understanding of entropy as it relates to the 2nd law of thermodynamics (primary misconception #2) is persistent among engineering students [8][28][32][37]. For example, Prince et al. [4] mentions that students incorrectly assume that friction and heat losses are the only limitations to achieving 100% thermal efficiency and fail to understand the impact of entropy on real systems. When students have a misconception about the definition of entropy, the misconception naturally leads to the inaccurate connection of entropy with the number of intermolecular interactions and collisions, mistakes with entropy changes in an isolated system, and, of course, treating entropy as only a measurement of disorder in a physical arrangement [36]. A secondary misconception exists for thermodynamics students, where the spontaneity of endothermic reactions are affected by entropy change [39].

The third most common primary misconception found in thermodynamics is that students confuse steady-state and equilibrium processes. The misconception likely begins with equilibrium, a concept that is grounded in the chemistry and chemical engineering disciplines. Vigeant et al. [40] reports that students misinterpret the difference between reaction rate and reaction equilibrium, and don't truly understand the descriptions of the chemical reactions underlying the two concepts. Similarly, students confuse the effect that the equilibrium constant has in indicating the rate of reactions [41]. In terms of secondary misconceptions, Foroushani [32] found that students confused the assumption of constant pressure and constant volume processes in energy analyses. This led to misunderstandings about function of state and function of path, as well as knowing the differences between boundary work, flow work, and shaft work when finding entropy (misconception #2).

Preventing and repairing common misconceptions in engineering thermodynamics begins with one of the concept inventories referenced previously [13][28]-[30] or a similar assessment tool. Yang et al. [1][9] investigated the use of schema training modules to repair misconceptions related to temperature and pressure, and prevent them in beginning engineering students. The study found that some students gained conceptual knowledge between pre-test and final test; the lack of significant gains indicating the difficulty in repairing robust misconceptions. Prince et al. [7][37] demonstrated improvements in student performance. The researchers used inquiry-based activities to repair misconceptions with heat, energy, and temperature representing primary misconception #1 found in this review.

Student misconceptions in fluid mechanics

Concept inventories and other assessments in fluid mechanics have also been developed and used to identify common student misconceptions [42]-[44]. In [44], Sudirman et al. identified student misconceptions by conducting a 4-level multiple choice test on static fluid material with 33 Physics education students. Another group of researchers identified misconceptions by administering a written test to students [43]. Brown et al. [45] identified misconceptions by interviewing 3 student cohorts, whereas other researchers used classroom observations [28][46]-[47]. The literature review revealed the following top 3 primary misconceptions:

1. Bernoulli's principle [28][43][46]-[47].
2. Gravitational effects (e.g., hydrostatic pressure, Archimedes' principle) [10][43]-[44][47].
3. Fluid statics (e.g., Pascal's law) [43]-[44][47].

The Bernoulli principle is primary misconception #1 and was one of the 31 concepts identified by Streveler et al. [28] as having lower understanding and higher importance relative to some other concepts evaluated. A significant issue for students lies in applying Bernoulli's equation for two points of a fluid where one point is at rest [43][47]. Suarez et al. [46] later found that students had trouble understanding that higher flow velocity does not always indicate lower pressure (a secondary misconception). For example, a student's experience with placing their finger on the end of a hose led them to believe that the higher velocity was a result of higher pressure. Another secondary misconception is that students assume that a moving volume element is affected only by the fluid that precedes it [46].

When students encounter questions involving gravity (primary misconception #2), they base their answers on ill-supported assumptions about local pressures [10][44]. Many students incorrectly generalize the behavior of point particles under the influence of gravity to the behavior of fluids. Some examples include misunderstandings around hydrostatic pressure, Archimedes' principle, and flow velocity changes in vertical pipes of uniform cross-section [44][47].

Primary misconception #3 involving fluid statics is that students struggle with applying Pascal's law, the negligible pressure differences between the extremities of a vertical pipe with a fluid at rest [43]-[44]. Some other notable misconceptions included topics related to pipe flow, such as flow through pipes with changing diameter and changing pressure [43][45], recognizing that the pressure of a fluid in motion is the same as the pressure of a fluid at rest [43], and applications of the ideal gas law [47].

Aside from the theme of identifying misconceptions held by students, the literature review also uncovered the theme of preventing and remediating common misconceptions around fluid mechanics. One of the most effective methods found was showing real-world examples or demonstrations so that students could debunk their own misconceptions in real time. For example, one set of instructors asked students several different questions, such as "do you need to blow harder or softer to blow large soap bubbles," with many students stating that one needs to blow harder [11]. Using real-life examples, these instructors were able to teach their students the correct knowledge behind fluid mechanics concepts. In [10], Schäfle and Kautz developed a tutorial based in student thinking, where students worked in groups to confront misconceptions with the continuity equation and the Bernoulli equation, the latter being the most common primary misconception related to fluid mechanics found in the literature.

Student misconceptions in heat transfer

Similar to the other two engineering subjects discussed previously, several researchers have developed concept inventories for assessing student misconceptions in heat transfer [14]-[16]. A review of the literature for the most common student misconceptions in heat transfer revealed that the top 3 primary misconceptions are:

1. Differentiation among heat, energy, and temperature [5][7][28][35][40][48].
2. Rate vs. amount of transfer [5][7][40][49].
3. Modes of heat transfer [7][28][35][40][50].

As was discovered for thermodynamics, students in heat transfer commonly and incorrectly equate heat, energy, and temperature or think of them as being interchangeable quantities [5][48]. Oftentimes, the primary misconception begins with heat and temperature because of the everyday observations a student encounters, such as the belief that temperature determines how “cool” or “warm” a body feels [5][7]. This leads students to confuse temperature and energy (secondary misconception), incorrectly assuming that higher temperatures always indicate higher energy [5][40]. Students may not understand that energy is a broader concept encompassing multiple forms, while temperature specifically measures the average kinetic energy of particles in a substance. Similarly, misunderstandings between heat and energy lead students to confuse thermal energy and its transfer (secondary misconceptions), leaving them unable to recognize that heat is one of the ways energy can be transferred [28][35].

Thus, in some ways the primary misconception #2 between heat transfer rate and amount of heat transferred is a secondary misconception to the heat, energy, and temperature primary misconception. Students fail to treat heat as a substance that is transferred between bodies, which is separate from the total amount of heat that is transferred [5][7][40]. This misunderstanding is not limited to heat transfer, but also arises as a secondary misconception for the concepts of momentum transfer and mass transfer [49]. The confusion leads to additional downstream effects, such as not knowing the correct units to use for each process [40]. Finally, primary misconception #3 is that students do not fully understand the different modes of heat transfer (conduction, convection, and radiation) and how they operate [28][50]. The most problematic issue concerns thermal radiation, where students think that the process requires a medium to transfer heat, similar to conduction and convection [15][40]. The concept of heat transfer through electromagnetic waves proves to be too cumbersome for most students to comprehend and apply to heat transfer problems.

Conclusions

This paper presented a systematic literature review on the common misconceptions within engineering thermodynamics, fluid mechanics, and heat transfer. The articles found were organized into a top 3 from each subject area based on the number of times each misconception was identified in the literature. The results for the most common primary misconceptions can be summarized as follows: thermodynamics (differentiation among heat, energy, and temperature, entropy, and steady-state vs. equilibrium processes); fluid mechanics (Bernoulli's principle, gravitational effects, and fluid statics), and heat transfer (differentiation among heat, energy, and temperature, rate vs. amount of transfer, and modes of heat transfer). This review also included a discussion about the distinction between primary and secondary misconceptions, where secondary misconceptions typically arose from a lack of addressing primary misconceptions (or robust misconceptions). Additionally, this review discussed the concept inventories that researchers have developed to identify and assess student misconceptions, and the methodologies available to assist instructors in repairing and preventing robust misconceptions. The results of this systematic literature review can be used to help engineering educators understand student misconceptions in their subject area, learn tools to enhance their teaching practices, and better support students with overcoming their misconceptions.

References

[1] D. Yang, R.A. Streveler, R.L. Miller, I. Senocak, and J. Slotta, "Using schema training to facilitate students' understanding of challenging engineering concepts in heat transfer and thermodynamics," *Journal of Engineering Education*, vol. 109 (4), pp. 743-759, Oct. 2020.

[2] M.T. Chi, "Commonsense conceptions of emergent processes: Why some misconceptions are robust," *The Journal of the Learning Sciences*, vol. 14 (2), pp. 161-199, 2005.

[3] J.N. Burgoon, M.L. Heddle, and E. Duran, "Re-examining the similarities between teacher and student conceptions about physical science," *Journal of Science Teacher Education*, vol. 22 (2), pp. 101-114, 2011.

[4] M.J. Prince, M.J.A. Vigeant, and K.E.K. Nottis, "Assessing misconceptions of undergraduate engineering students in the thermal sciences," *International Journal of Engineering Education*, vol. 26 (4), pp. 880-890, 2010.

[5] B.P. Self, R.L. Miller, A. Kean, T.J. Moore, T. Ogletree, and F. Schreiber, "Important student misconceptions in mechanics and thermal science: Identification using model-

eliciting activities," in *38th ASEE/IEEE Frontiers in Education Conference*, Saratoga Springs, NY, USA, Oct. 22-25, 2008.

[6] D.E. Meltzer, "Investigation of students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course," *American Journal of Physics*, vol. 72 (11), pp. 1432-1446, Nov. 2004.

[7] M.J. Prince, M.A. Vigeant, and K.E.K. Nottis, "The use of inquiry-based activities to repair student misconceptions related to heat, energy and temperature," in *2011 ASEE Annual Conference & Exposition*, Vancouver, BC, CA, June 26-29, 2011.

[8] M.J. Prince, M.J.A. Vigeant, and K.E.K. Nottis, "Assessment and repair of critical misconceptions in engineering heat transfer and thermodynamics," in *2013 ASEE Annual Conference & Exposition*, Atlanta, GA, USA, June 23-26, 2013.

[9] D. Yang, R.A. Streveler, R.L. Miller, and A.I.S. Román, "Repairing misconceptions: A case study with advanced engineering students on their use of schema training modules," in *2009 ASEE Annual Conference & Exposition*, Austin, TX, USA, June 14-17, 2009.

[10] C. Schäfle and C. Kautz, "Students reasoning in fluid dynamics: Bernoulli's principle vs. the continuity equation," *Proceedings of the 10th international conference on Physics Teaching in Engineering Education*, pp. 1-8, May 2019.

[11] N.B. Kaye and J. Ogle, "Overcoming misconceptions and enhancing student's physical understanding of civil and environmental engineering fluid mechanics," *Physics of Fluids*, vol. 34 (4), Apr. 2022.

[12] K.C. Midkiff, T.A. Litzinger, and D.L. Evans, "Development of engineering thermodynamics concept inventory instruments," in *31st ASEE/IEEE Frontiers in Education Conference*, Reno, NV, USA, Oct. 10-13, 2001.

[13] B.D. Gane, D. Denick, N. Jorion, L.V. DiBello, J.W. Pellegrino, and R.A. Streveler, "Continuous improvement of a concept inventory: Using evidence-centered design to refine the thermal and transport concept inventory," in *2015 ASEE Annual Conference & Exposition*, Seattle, WA, USA, June 14-17, 2015.

[14] A. Jacobi, J. Martin, J. Mitchell, and T. Newell, "A concept inventory for heat transfer," in *33rd ASEE/IEEE Frontiers in Education Conference*, Westminster, CO, USA, Nov. 5-8, 2003.

[15] M. Prince, M. Vigeant, and K. Nottis, "Development of a concept inventory in heat transfer," in *2009 ASEE Annual Conference & Exposition*, Austin, TX, USA, June 14-17, 2009.

[16] J. Martin, J. Mitchell, and T. Newell, "Development of a concept inventory for heat transfer," in *33rd ASEE/IEEE Frontiers in Education Conference*, Westminster, CO, USA, Nov. 5-8, 2003.

[17] S.R. Turns, P.N. Van Meter, T.A. Litzinger, and C.M. Firetto, "Development of an intervention to improve students' conceptual understanding of thermodynamics," in *2013 ASEE Annual Conference & Exposition*, Atlanta, GA, USA, June 23-26, 2013.

[18] S. Kesidou and R. Duit, "Students' conceptions of the second law of thermodynamics – An interpretive study," *Journal of Research in Science Teaching*, vol. 30 (1), pp. 85-106, Jan. 2006.
[19] W. Dempster, C.K. Lee, and J.T. Boyle, "Teaching thermodynamics and fluid mechanics using interactive learning methods in large classes," in *2002 ASEE Annual Conference & Exposition*, Montreal, Quebec, CA, June 16-19, 2002.
[20] K.J. Nasr and B. Ramadan, "Implementation of problem-based learning into engineering thermodynamics," in *2005 ASEE Annual Conference & Exposition*, Portland, OR, USA, June 12-15, 2005.
[21] D. Baker, O. Ezekoye, P. Schmidt, C. Jones, and M. Liu, "ThermoNet: A web-based learning resource for engineering thermodynamics," in *2002 ASEE Annual Conference & Exposition*, Montreal, Quebec, CA, June 16-19, 2002.
[22] K.L. Tuttle and C. Wu, "Computer-based thermodynamics," *Journal of Educational Technology Systems*, vol. 30 (4), pp. 427-436, June 2002.
[23] P. Tebbe, S. Ross, M. Ostendorf, and S. Cray, "Promoting student engagement in thermodynamics with engineering scenarios (Year 2)," in *2009 ASEE Annual Conference & Exposition*, Austin, TX, USA, June 14-17, 2009.
[24] T.J. Reagan, S. Claussen, and E. Lyne, "Systematic review of rigorous research in teaching introductory circuits," in *2020 ASEE Annual Conference & Exposition*, Virtual Meeting, June 22-26, 2020.
[25] N. Sambamurthy and A.D. Edgcomb, "A systematic literature review of misconceptions in linear circuit analysis," in *2018 ASEE Annual Conference & Exposition*, Salt Lake City, UT, USA, June 23-27, 2018.
[26] A. Rodriguez, L. Fogg, A. Clark, J.L. Welter, G. Sirokman, and R. Barlow, "Literature survey of how students with visual impairments interact with engineering course materials," in *2023 ASEE Annual Conference & Exposition*, Baltimore, MD, USA, June 25-28, 2023.
[27] J. Richardson, "Concept inventories: Tools for uncovering STEM students' misconceptions," *Invention and Impact: Building Excellence in Undergraduate Science, Technology, Engineering and Mathematics (STEM) Education*, American Association for the Advancement of Science, 2012.
[28] R.A. Streveler, B.M. Olds, R.L. Miller, and M.A. Nelson, "Using a Delphi study to identify the most difficult concepts for students to master in thermal and transport science," in *2003 ASEE Annual Conference & Exposition*, Nashville, TN, USA, June 22-25, 2003.
[29] R.L. Miller, R.A. Streveler, M.A. Nelson, M.R. Geist, and B.M. Olds, "Developing an instrument to measure engineering student misconceptions in thermal and transport science," *Journal of Engineering Education*, 2008.
[30] B.M. Olds, R.A. Streveler, R.L. Miller, and M.A. Nelson, "Preliminary results from the development of a concept inventory in thermal and transport science," in *2004 ASEE Annual Conference & Exposition*, Salt Lake City, UT, USA, June 20-23, 2004.

[31] H. Saricayir, S. Ay, A. Comek, G. Cansiz, and M. Uce, "Determining students' conceptual understanding level of thermodynamics," *Journal of Education and Training Studies*, vol. 4 (6), pp. 69-79, Mar. 2016.
[32] S. Foroushani, "Misconceptions in engineering thermodynamics: A review," *International Journal of Mechanical Engineering Education*, vol. 47 (3), pp. 195-209, 2019.
[33] M. Bozzi, P. Ghislandi, K. Tsukagoshi, M. Matsukawa, M. Wada, N. Nagaoka, A.B. Pnev, A.A. Zhirnov, G. Guillerme, and M. Zani, "Highlight misconceptions in physics: A T.I.M.E. project," *Proceedings of INTED2019 Conference*, pp. 2520-2525, Mar. 2019.
[34] R.L. Miller, R.A. Streveler, M.A. Nelson, M.R. Geist, and B.M. Olds, "Concept inventories meet cognitive psychology: Using beta testing as a mechanism for identifying engineering student misconceptions," in *2005 ASEE Annual Conference & Exposition*, Portland, OR, USA, June 12-15, 2005.
[35] 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 (3), pp. 203-210, July 2011.
[36] M. Sozbilir and J.M. Bennett, "A study of Turkish chemistry undergraduates' understandings of entropy," *Journal of Chemical Education*, vol. 84 (7), pp. 1204-1208, July 2007.
[37] M. Vigeant, M.J. Prince, and K.E.K. Nottis, "Inquiry-based activities to repair misconceptions in thermodynamics and heat transfer," in *2009 ASEE Annual Conference & Exposition*, Austin, TX, USA, June 14-17, 2009.
[38] I.C. Hadfield and C.E. Wieman, "Student interpretations of equations related to the first law of thermodynamics," *Journal of Chemical Education*, vol. 87 (7), pp. 750-755, May 2010.
[39] B. Sreenivasulu and R. Subramaniam, "University students understanding of chemical thermodynamics," *International Journal of Science Education*, vol. 35 (4), pp. 601-635, June 2012.
[40] M. Vigeant, M.J. Prince, K.E.K. Nottis, and R.L. Miller, "Inquiry-based activities to address critical concepts in chemical engineering," in *2011 ASEE Annual Conference & Exposition*, Vancouver, BC, CA, June 26-29, 2011.
[41] M. Sozbilir, T. Pynarbaþy, and C.N. Nurtac, "Prospective chemistry teachers' conceptions of chemical thermodynamics and kinetics," *Eurasia Journal of Mathematics, Science & Technology Education*, vol. 6 (2), pp. 111-120, June 2010.
[42] J. Martin, J. Mitchell, and T. Newell, "Development of a concept inventory for fluid mechanics," in *33rd ASEE/IEEE Frontiers in Education Conference*, Westminster, CO, USA, Nov. 5-8, 2003.
[43] A. Suarez, S. Kahan, G. Zavala, and A.C. Marti, "Students conceptual difficulties in hydrodynamics," *Physical Review Physics Education Research*, vol. 13, Nov. 2017.
[44] S. Sudirman, N.J. Ningsih, S. Saparini, M. Ariska, N. Andriani, and A. Pasaribu, "The identification of misconceptions of physics education students at Universitas Sriwijaya

using four-tier diagnostic test on static fluid material," *Journal of Mathematics, Science, and Computer Education*, vol. 3 (2), pp. 26-33, Aug. 2023.

[45] S.A. Brown, K. Beddoes, D. Montfort, and A. Baghdanov, "Engineering students' fluid mechanics misconceptions: A description and theoretical explanation," *International Journal of Engineering Education*, vol. 33 (4), pp. 1149-1162, Jan. 2017.

[46] A. Suarez, M. Monteiro, M. Dutra, and A.C. Marti, "Bernoulli's muddle: A research on students' misconceptions in fluid dynamics," *Modelling in Science Education and Learning*, vol. (1), pp. 1-13, 2020.

[47] D.G. Huilier, "Forty years' experience in teaching fluid mechanics at Strasbourg University," *Fluids*, vol. 4 (4), p. 199, 2019.

[48] K.E.K. Nottis, M.J. Prince, and M.A. Vigeant, "Building an understanding of heat transfer concepts in undergraduate chemical engineering courses," *US–China Education Review*, vol. 7 (2), pp. 1-9, Feb. 2010.

[49] R.L. Miller, R.A. Streveler, B.M. Olds, M.T.H. Chi, M.A. Nelson, and M.R. Geist, "Misconceptions about rate processes: Preliminary evidence for the importance of emergent conceptual schemas in thermal and transport sciences," in *2006 ASEE Annual Conference & Exposition*, Chicago, IL, USA, June 18-21, 2006.

[50] S.R. Pathare and H.C. Pradhan, "Students' misconceptions about heat transfer mechanisms and elementary kinetic theory," *Physics Education*, vol. 45 (6), pp. 629-634, 2010.