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Students' Problem-Solving Skills and Gender-Based Comparison in Thermodynamics through the STEM Approach

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ABSTRACT

Problem-solving skills through the STEM approach are currently also being examined in relation to gender differences. This study aims to describe students' problem-solving skills and compare them based on gender in the topic of thermodynamics using the STEM approach. The research employed a descriptive quantitative method involving 86 grade 11 science students, consisting of 51 female and 35 male students. The problem-solving indicators used include Useful Description, Physics Approach, Specific Application of Physics, Mathematical Procedure, and Logical Progression. Data were analyzed using descriptive statistics and comparative tests. The results showed that, in general, students' problem-solving abilities were in the "good" category. The comparative analysis revealed that female students outperformed male students in the Useful Description and Logical Progression indicators, while male students showed higher performance in Specific Application of Physics and Mathematical Procedure. No significant difference was found between the two groups in the Physics Approach indicator. Overall, the total score of students' problem-solving skills indicated no significant difference between female and male students. These findings suggest that the STEM approach fosters equitable opportunities for both genders to develop physics problem-solving skills. Recommendations include applying scaffolded problem-solving and cooperative learning to support gender-specific strengths in logic and application.

INTRODUCTION

Problem-solving ability is one of the essential competencies in science education, particularly in physics, as it requires students not only to comprehend concepts but also to apply them in real-life contexts (Daniel, 2016; Hebebci & Usta, 2022). In the context of 21st-century education, this skill falls under the category of higher-order thinking skills (HOTS), which support the development of critical and creative thinking abilities (Brookhart, 2010; Collins, 2014). Physics as a discipline demands not only theoretical understanding but also the practical application of concepts in everyday situations (English, 2023; Tan et al., 2023). Therefore, problem-solving ability serves not only as an indicator of learning success but also as a measure of how well students can integrate knowledge, skills, and thinking

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strategies in addressing context-based scientific problems (Daniel, 2016; Hebebci & Usta, 2022).

At the senior high school level, various studies have shown that most students still encounter difficulties in solving physics-related problems (Docktor et al., 2015; M. Vijaya & Buncha, 2017; Qotrunnada, 2022). These challenges not only caused by weak mastery of fundamental concepts, but also by a lack of familiarity with using systematic and reflective thinking strategies (Docktor et al., 2015, 2016). Common issues observed in classroom settings include students' reliance on formulas without understanding the underlying concepts, poor analytical skills in interpreting problem information, and limited ability to design and evaluate alternative solutions. Thus, it is crucial for students to develop problem-solving skills to enable them to analyze situations, devise solutions, and evaluate outcomes logically and systematically within the framework of physics education.

One of the topics in physics that demands a high level of problem-solving ability is thermodynamics (Aziz et al., 2014; Liana et al., 2020; Turns & Van Meter, 2011). This topic involves abstract and mathematical concepts such as energy, heat, temperature, entropy, and the laws of thermodynamics (Bain et al., 2014; D. E. Meltzer, 2004). Students often struggle to understand the interrelationships among these concepts and to apply them in calculations and physical contexts (Brown & Singh, 2022; Jewaru et al., 2022, 2023). Research by Christensen et al. (2009) and Meltzer (2002) indicated that a strong conceptual understanding in physics, including thermodynamics, significantly influences students' success in problem-solving. Misconceptions regarding the laws of thermodynamics negatively affect students' performance in solving physics problems (Foroushani, 2019; Tatar & Oktay, 2011). Therefore, it is crucial to map students' problem-solving abilities not only based on their final answers but also by examining their underlying thought processes, as these may vary depending on individual characteristics.

In the pedagogical context, gender based differences in students' characteristics have also become a focus of problem-solving research (Armando et al., 2022; Taasoobshirazi & Carr, 2008). Male and female students often demonstrate different tendencies in cognitive styles, problem-solving strategies, and levels of confidence when facing challenging tasks (Balta & Asikainen, 2019; Wider & Wider, 2023). For instance, male students tend to be more exploratory in testing various solution alternatives while female students are generally more cautious and meticulous during the problem-solving process (Armando et al., 2022; Wider & Wider, 2023). However, these findings remain inconsistent and highly contextual, influenced by factors such as the learning environment, instructional approaches, and the types of problems presented. Thus, it is important to conduct empirical investigations to determine whether significant gender-based differences exist in students' problem-solving abilities, particularly in complex physics topics such as thermodynamics.

The STEM approach in physics education has emerged as a response to the demands of modern education, which requires interdisciplinary integration to solve real-world problems (Priemer et al., 2020; Tan et al., 2023). By combining the elements of science, technology, engineering, and mathematics (Nugent et al., 2015), this approach encourages students to think critically, creatively, and systematically when confronted with learning challenges (English, 2023). In the context of thermodynamics, which involves both conceptual and practical components, the STEM approach provides students with opportunities to explore concepts through projects or experiments that are relevant to everyday life. This helps students establish meaningful connections between science and their real-world experiences (English, 2023; Tan et al., 2023). Consequently, this approach not only reinforces students' conceptual understanding of physics but also enhances their overall problem-solving abilities (Hebebci & Usta, 2022).

Several studies have examined gender differences in problem-solving skills and their relation to the STEM approach: 1) Female students have been found to be more influenced by the gender of their partners in solving physics problems, making mixed-gender collaborations potentially disadvantageous for female students in physics learning (Ding & Harskamp, 2006); 2) No significant gender-based differences in problem-solving ability were observed in introductory physics courses (Balta & Asikainen, 2019); 3) Female students demonstrated higher levels of problem-solving ability compared to male students (Istiyono et al., 2019), and Wider (2023) found that, in general, male students exhibit stronger physics problem-solving skills than their female counterparts; 4) Pre-college female STEM students scored lower in physics achievement and comprehension than their male counterparts (Khan et al., 2022; Sagala et al., 2019); (5) There were no performance differences between male and female students at the secondary level when applying the STEM-PjBL (Project-Based Learning) approach, as measured through achievement in physics mechanics tests (Samsudin et al., 2019).

In the context of physics education, studies examining gender differences in problem-solving abilities remain limited, particularly in the subject of thermodynamics. Furthermore, there is a lack of research utilizing the STEM approach to investigate differences in each indicator of students' problem-solving skills within thermodynamics content. Therefore, exploring this aspect is essential to promote more adaptive instruction that accommodates the diverse characteristics of students.

Based on this background, the present study aims to describe students' problem-solving skills using the STEM approach in thermodynamics and to analyze the differences in these skills based on gender. This research is expected to contribute to the development of more effective and responsive physics instruction that aligns with the varied needs of students.

METHODS

This study employed a descriptive quantitative design aimed at describing and comparing students' problem-solving abilities based on gender in the topic of thermodynamic laws using the STEM approach (English, 2023; Nugent et al., 2015). The four core components of STEM: 1) Science, through the understanding of thermodynamic concepts and laws; 2) Technology, through the use of temperature measuring tools, tire pumps, and digital simulations; 3) Engineering, through the design and construction of prototypes; and 4) Mathematics, through the calculation of energy efficiency, unit conversions, and analysis of experimental data.

The subjects of this study were Grade 11 science students from three classes at a senior high school. Subject selection was conducted through non-random purposive sampling based on recommendations from the physics teacher, considering both the completion of the thermodynamics topic and the implementation of the STEM approach in the classroom. A total of 86 students participated in this study, consisting of 51 female students and 35 male students.

The instrument used in this study was a set of structured proble solving questions designed based on five problem solving skill (PSS) indicators (Docktor et al., 2016), namely: 1) Useful Description (PSS-I1); 2) Physics Approach (PSS-I2); 3) Specific Application of Physics (PSS-I3); 4) Mathematical Procedure (PSS-I4); and 5) Logical Progression (PSS-I5). Students' responses were assessed using a rubric adapted from Docktor et al. (2016) problem-solving analysis rubric, employing a scoring scale ranging from 0 to 4 for each indicator. The results of the reliability test on the problem solving question instrument obtained a Cronbach's Alpha of 0.722.

The total problem-solving score obtained was then converted into a percentage to determine the category of students' achievement in meeting the problem-solving indicators. The categorization criteria were based on Table 1 (Budiyono, 2015).

Table 1. The Conversion of the Students' Achievement of Indicators

Percentage Interval (%)	Category
80 ≤ x ≤ 100	Very good
60 ≤ x < 80	Good
40 ≤ x < 60	Enough
20 ≤ x < 40	Poor
0 ≤ x < 20	Very poor

RESULTS AND DISCUSSION

Students' Problem-Solving Skills in Thermodynamics through the STEM Approach

Descriptive analysis of students' problem-solving abilities on the topic of thermodynamics using the STEM approach revealed that the majority of students fell within the medium to low categories across all indicators. Although the instruction was conducted using the STEM approach (Nugent et al., 2015), which integrates science, technology, engineering, and mathematics, students still exhibited significant challenges in several key aspects of problem solving. Figure 1 shows the frequency of students' scores across five categories, and table 2 presents the profile of students' problem-solving skills.

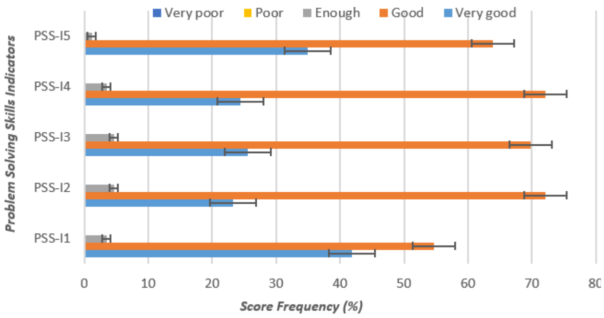

Figure 1. The frequency of students' scores across five categories

The Useful Description Indicator (PSS-I1), as shown in Figure 1, indicates that the majority of students (54.65%) fell into the "Good" category, while only a small percentage reached the "Very Good" and "Enough" categories. This finding aligns with the data in Table 2, which shows that only 7.91% of students were able to provide a complete and accurate description, while 50% fell into the category of descriptions with minor deficiencies. The dominance in the "Good" category indicates that students possess basic skills in describing problems but still require reinforcement in identifying variables, initial conditions, and problem objectives, which are crucial for understanding the laws of thermodynamics in a contextual manner (Docktor et al., 2015; Jewaru et al., 2023).

In the context of thermodynamic laws, a useful description includes an understanding of the system, the surroundings, and quantities such as temperature, heat, work, and internal energy. However, a common error observed among students was their failure to assign symbols to each known quantity and to include the values of those symbols based on information provided in the problem. Students struggled to describe essential information related to the First Law of Thermodynamics, often confusing temperature with heat or perceiving heat as temperature rather than a form of energy. These difficulties indicate that students have not yet fully developed the ability to explicitly connect real-world phenomena with thermodynamic concepts (Bain et al., 2014; Jewaru et al., 2022).

The ability to represent a problem accurately is foundational in the physics problem-solving process (Docktor et al., 2016), as it serves as the basis for selecting an appropriate conceptual approach. Within the STEM approach, this phase corresponds to the problem identification stage in the engineering design process. This skill is highly important, as it directly relates to higher-order thinking competencies, which are among the core goals of the STEM approach (Jewaru et al., 2023; Samsudin et al., 2019).

The Physics Approach indicator (PSS-I2) revealed a dominance in the "Good" category and a low proportion of students in the

Tabel 2. Students' Problem-Solving Skills Profile

Indicators	Category	Percentage Frequency (%)
Useful Description	The description is useful, appropriate, and complete.	7.91
	The description is useful but contains minor omissions or errors.	50.00
	Parts of the description are not useful, missing, and/or contain errors.	40.70
	Most of the description is not useful, missing, and/or contains errors.	1.40
	The entire description is not useful and/or contains errors.	0.00
Physics Approach	The physics approach is appropriate and complete.	1.63
	The physics approach contains minor omissions or errors.	33.49
	Some concepts and principles of the physics approach are missing and/or inappropriate.	61.40
	Most of the physics approach is missing and/or inappropriate.	3.49
	All of the chosen concepts and principles are inappropriate	0.00
Specific Application of Physics	The specific application of physics is appropriate and complete.	1.40
	The specific application of physics contains minor omissions or errors.	22.33
	Parts of the specific application of physics are missing and/or contain errors.	60.70
	Most of the specific application of physics is missing and/or contains errors.	15.35
	The entire specific application is inappropriate and/or contains errors.	0.23
Mathematical Procedure	The mathematical procedures are appropriate and complete.	8.60
	Appropriate mathematical procedures are used with minor omissions or errors.	60.70
	Parts of the mathematical procedures are missing and/or contain errors.	29.77
	Most of the mathematical procedures are missing and/or contain errors.	0.93
	All mathematical procedures are Inappropriate and/or contain errors.	0.00
Logical Progression	The entire problem solution is clear, focused, and logically connected.	7.91
	The solution is clear and focused with minor inconsistencies.	47.21
	Parts of the solution are unclear, unfocused, and/or inconsistent.	40.93
	Most of the solution parts are unclear, unfocused, and/ or inconsistent.	3.95
	The entire solution is unclear, unfocused, and/ or inconsistent.	0.00

"Very Good" category, indicating that most students have not yet mastered the selection of appropriate thermodynamic principles based on the context of the problems. As shown in Table 2, the majority of students (61.40%) were only able to apply physics approaches partially or inaccurately, while only 1.63% of students applied a complete and correct approach. In the context of thermodynamic laws, an appropriate approach involves selecting the correct thermodynamic law and understanding or utilizing P–V diagrams, as well as identifying processes such as isochoric, isobaric, and isothermal transformations. Students exhibited uncertainty in determining relevant concepts and applying the correct physical principles to solve thermodynamics problems. This contributed to their inability to identify appropriate formulas or initial concepts (Foroushani, 2019; Jewaru et al., 2022; D. E. Meltzer, 2004). Such difficulty in choosing relevant principles reflects weak conceptual understanding, one of the key characteristics of students who have not yet developed proficiency in physics-based problem-solving (Heller & Heller, 2010; D. Meltzer, 2008). In STEM-based instruction, mastery of scientific concepts and principles is a critical starting point for integration into technological and engineering contexts. A lack of deep understanding of thermodynamic principles prevents students from effectively linking real-world phenomena with scientifically valid solutions (Docktor et al., 2016).

The Specific Application of Physics indicator (PSS-I3) shows that most students were still in the "Good" category, though the frequencies of "Enough" and "Poor" were higher compared to indicators PSS-I1 and PSS-I2. Only a small number of students were able to reach the "Very Good" category, reflecting a low level of ability to apply physics laws in solving real and contextual problems. A total of 60.70% of students provided only partial and inconsistent physics applications, while 15.35% presented largely incorrect applications. This suggests that students struggled to transfer selected concepts into the context of concrete problems, particularly in the quantitative or interpretative aspects of thermodynamic processes. Within the STEM approach, this skill is critical as it relates to the application phase transferring solutions into real-world contexts as emphasized in the integrative STEM model (Nugent et al., 2015). The ability to apply concepts in authentic situations represents a form of problem-solving transfer, a key indicator that students not only understand concepts but are also able to adapt them across various contexts (Docktor et al., 2015; Jewaru et al., 2022, 2023). If the STEM approach fails to foster this skill, improvements in instructional design are necessary such as enhancing project-based or structured inquiry approaches that genuinely engage students in solving authentic problems (Samsudin et al., 2019).

The Mathematical Procedure indicator (PSS-I4), as illustrated in the graph, shows a relatively high proportion of students in the "Good" and "Very Good" categories, higher than in the other indicators. This aligns with the tabulated data, which indicate that 60.70% of students performed well in mathematical procedures, while 8.60% completed them perfectly. These results suggest that students' computational and mathematical manipulation skills are relatively strong, likely supported by the routine practice of problem-solving commonly applied in conventional physics instruction. However, strong mathematical ability does not necessarily reflect conceptual understanding. Docktor & Mestre, (2014) argue that students may be able to solve mathematical problems correctly without truly understanding the physical meaning of the parameters involved. As a result, correct procedures may mask underlying misconceptions.

The Logical Progression indicator (PSS-I5) revealed a dominance in the "Good" category, but also a notable proportion of students fell into the "Enough" and "Poor" categories, as shown in the graph. This is supported by the tabulated data, in which 47.21% of students demonstrated solutions that were somewhat logical but lacked consistency. Only 7.91% of students exhibited a complete, coherent, and systematic line of reasoning.

These findings indicate that, although students were able to solve parts of the problem, they often failed to connect the steps in a logical sequence or to draw conclusions that were well-integrated with the initial data. Within the STEM approach, this indicator is closely related to the stages of evaluating and presenting solutions, critical components in developing scientific communication and reflective design (Balta & Asikainen, 2019; Nugent et al., 2015).

Comparison of Students' Problem-Solving Skills on Thermodynamics through the STEM Approach Based on Gender

As part of the comparative analysis, a statistical test was conducted as presented in Table 3 to determine whether there were significant differences in problem-solving abilities between female and male students based on the five problem-solving skill indicators (Docktor et al., 2016).

Tabel 3. Comparison of Students' Problem-Solving Skills based on Gende

	Gender	p-values	Mean	Interpretation	effect sizes
Usefull Description (PSS-I1)	Female	0.001	79.40	Significant differences	0.727 (medium effect)
	Male		73.08		
Physics Approch (PSS-I2)	Female	0.719	73.77	no significant difference	0.075 (small effect)
	Male		73.10		
Specifics Application of Physics (PSS-I3)	Female	0.000	68.67	Significant differences	1.018 (very large effect)
	Male		77.47		
Mathematical Procedure (PSS-I4)	Female	0.011	73.03	Significant differences	0.470 (medium effect)
	Male		76.36		
Logical Progression (PSS-I5)	Female	0.000	79.13	Significant differences	1.078 (very large effect)
	Male		69.78		
Total Score of PSS	Female	0.619	74.80	no significant difference	0.227 (weak effect)
	Male		73.96		

Based on Table 3, the PSS-I1 indicator shows that female students outperformed their male counterparts in identifying information, describing initial conditions, and constructing comprehensive representations of the problem. Within the STEM approach, this phase corresponds to the stages of problem identification and ideation, which serve as a critical foundation in the design of engineering solutions. This result is consistent with the findings of Arroyo et al. (2013) and Istiyono et al. (2019), who reported that female students tend to demonstrate greater precision and attentiveness when observing problems in detail, an advantage in the initial stages of problem-solving.

The PSS-I2 indicator reveals that both female and male students experienced relatively similar difficulties in selecting appropriate physical laws or principles, particularly the first and second laws of thermodynamics. This similarity suggests that conceptual understanding of physics has not yet been fully developed in either group. In practice, STEM implementation in classrooms often emphasizes project work and technical execution over explicit conceptual instruction in thermodynamics (Jewaru et al., 2023). This finding is supported by Docktor et al. (2016), who emphasized that conceptual understanding in physics requires instruction grounded in visualization, experimentation, and in-depth discussion, elements that are sometimes underrepresented in classroom STEM practices.

The PSS-I3 indicator shows that male students outperformed female students in the specific application of thermodynamic principles to problem-solving. This skill is closely related to the implementation and technical design stages within the STEM approach, which typically involve the use of tools, hands-on experiments, or mathematical modeling of physical phenomena. Male students often exhibit a preference for exploratory and technical activities, which may explain their dominance in this indicator (Wider & Wider, 2023). In contrast, female students tend to demonstrate stronger initial understanding and systematic thinking structures, as reflected in the PSS-I1 and PSS-I2 indicators. This suggests that although female students have a solid conceptual understanding of physics, they may benefit from learning strategies that are more conceptual, visual, or guided-exploration-based to better express their understanding in an applied context.

The PSS-I4 indicator indicates that male students show a stronger tendency in using formulas, organizing calculations, and systematically manipulating mathematical expressions. These skills are particularly important within the STEM context, especially in mastering aspects of quantitative reasoning. This finding reinforces previous research by Wider (2023) and Ganley (2016), which showed that male students often display greater confidence in mathematical tasks, although this does not necessarily imply stronger conceptual understanding. In practice, male students frequently perform better in symbol and number-based tasks, particularly when instructional approaches emphasize calculation and quantitative logic. Female students, on the other hand, tend to approach problem-solving more cautiously or require more time for computation, which can slow down their performance in algebraic manipulation and complex calculations, despite having a conceptual understanding of the purpose behind the procedure.

The PSS-I5 indicator demonstrates that female students are more capable of organizing problem-solving steps in a systematic, coherent, and logical manner from beginning to end. Within the STEM approach, logical reasoning in solutions is particularly important during the testing and evaluation stages, where students are required to assess whether the proposed solution aligns with the initial data and objectives. Docktor & Mestre (2014) emphasized that the ability to communicate the reasoning process is a strong indicator of scientific thinking maturity, and this result suggests that female students excel in this aspect. In contrast, although male students may outperform in technical aspects such as concept application or mathematical procedures, the findings indicate that they tend to exhibit less consistent or less clearly communicated reasoning in their overall solutions.

According to the total Score of Problem-Solving Skills (PSS) presented in Table 4, there is no significant difference between female and male students through STEM approach (Balta & Asikainen, 2019; Samsudin et al., 2019). This indicates that although variations exist across individual indicators, the overall problem solving skills are relatively equivalent across genders. These findings suggest that the implementation of STEM based learning in the classroom has provided a relatively equitable space for both genders to develop scientific thinking skills, conceptual, procedural, and logical.

The STEM approach is designed to integrate interdisciplinary skills that reflect real scientific practice, such as formulating problems, designing solutions, applying concepts, and procedures systematically (English, 2023; Priemer et al., 2020; Tan et al., 2023). In the context of physics learning, STEM not only emphasizes conceptual understanding, but also applicative skills, logical thinking, and collaborative work. These characteristics allow the STEM approach to be an equitable space for both genders to develop their respective cognitive strengths. Therefore, STEM-based learning has the potential to balance and strengthen physics problem-solving abilities between genders through activities that are conceptually and procedurally integrated.

CONCLUSION AND SUGGESTION

Students' problem-solving skills on the topic of thermodynamics through the STEM approach were generally categorized as "Good." The profile of students' skills demonstrated a varied distribution across all indicators, with individual differences showing distinct areas of strength. Students tended to perform better in the Useful Description aspect, yet still required reinforcement in the Specific Application of Physics indicator, which involves applying physics concepts within problem contexts.

The gender-based comparison revealed significant differences in several indicators. Female students outperformed in Useful Description and Logical Progression, reflecting strong abilities in understanding problems and constructing solutions in a coherent sequence. In contrast, male students showed greater strength in Specific Application of Physics and Mathematical Procedure, indicating stronger performance in applying physics concepts and executing calculations.

The recommendation for educators is to apply scaffolded problem-solving in solving physics problems, especially in mathematical aspects and application of concepts. The use of cooperative learning is also important to accommodate the strengths of each gender, such as female students' logistical thinking abilities and male students' applied abilities.

AUTHOR CONTRIBUTIONS

AA designed the research framework, wrote the initial draft of the manuscript, refined the methodology, and reviewed the manuscript for intellectual content. SH conducted data collection in senior high schools. MT carried out the literature review and assisted in analyzing students' problem-solving profiles. MS performed statistical analysis and interpreted the gender-based comparison results. P validated the findings, organized the references, and provided critical revisions to the final manuscript.

REFERENCES

Armando, M., Ochs, M., & Régner, I. (2022). The Impact of Pedagogical Agents' Gender on Academic Learning: A Systematic Review. *Frontiers in Artificial Intelligence*, *5*(June), 1–23. https://doi.org/10.3389/frai.2022.862997

Arroyo, I., Burleson, W., Tai, M., Muldner, K., & Woolf, B. P. (2013). Gender differences in the use and benefit of advanced learning technologies for mathematics. *Journal of Educational Psychology*, *105*(4), 957–969. https://doi.org/10.1037/a0032748

Aziz, M. S., Zain, A. N. M., Samsudin, M. A. Bin, & Saleh, S. B. (2014). The impact of PBL on Undergraduate Physics Students' Understanding of Thermodynamics. *International Journal of Academic Research in Economics and Management Sciences*, *3*(4). https://doi.org/10.6007/ijarems/v3-i4/1088

Bain, K., Moon, A., Mack, M. R., & Towns, M. H. (2014). *Research and Practice of thermodynamics at the university level*. 320–335. https://doi.org/10.1039/c4rp00011k

Balta, N., & Asikainen, M. A. (2019). Introductory students' attitudes and approaches to physics problem solving: Major, achievement level and gender differences. *Journal of Technology and Science Education*, *9*(3), 378–387. https://doi.org/10.3926/JOTSE.666

Brookhart, S. M. (2010). *How to assess higher-order thinking skills in your classroom*. ASCD.

Brown, B., & Singh, C. (2022). Student understanding of thermodynamic processes, variables and systems. *European Journal of Physics*, *43*(5). https://doi.org/10.1088/1361-6404/ac7af2

Budiyono. (2015). *Statistika untuk Penelitian*. UNS Press.

Christensen, W. M., Meltzer, D. E., & Ogilvie, C. A. (2009). Student ideas regarding entropy and the second law of thermodynamics in an introductory physics course. *American Journal of Physics*, *77*(10), 907–917. https://doi.org/10.1119/1.3167357

Collins, R. (2014). Skills for the 21st Century: teaching higher-order thinking. Curriculum & Leadership Journal, 12 (14). *Curriculum & Leadership Journal*, *12*(14), 31.

Daniel, E. (2016). The Usefulness of Qualitative and Quantitative Approaches and Methods in Researching Problem-Solving Ability in Science Education Curriculum. *Journal of Education and Practice*, *7*(15), 91–100. https://doi.org/2222-288X

Ding, N., & Harskamp, E. (2006). How partner gender influences female students' problem solving in physics education. *Journal of Science Education and Technology*, *15*(5–6), 331–343. https://doi.org/10.1007/s10956-006-9021-7

Docktor, J. L., Dornfeld, J., Frodermann, E., Heller, K., Hsu, L., Jackson, K. A., Mason, A., Ryan, Q. X., & Yang, J. (2016). Assessing student written problem solutions: A problem-solving rubric with application to introductory physics. *Physical Review Physics Education Research*, *12*(1), 1–18. https://doi.org/10.1103/PhysRevPhysEducRes.12.010130

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics - Physics Education Research*, *10*(2), 1–58. https://doi.org/10.1103/PhysRevSTPER.10.020119

Docktor, J. L., Strand, N. E., Mestre, J. P., & Ross, B. H. (2015). Conceptual problem solving in high school physics. *Physical Review Special Topics - Physics Education Research*, *11*(2), 1–13. https://doi.org/10.1103/PhysRevSTPER.11.020106

English, L. D. (2023). Ways of thinking in STEM-based problem solving. *ZDM - Mathematics Education*, *55*(7), 1219–1230. https://doi.org/10.1007/s11858-023-01474-7

Foroushani, S. (2019). Misconceptions in engineering thermodynamics: A review. *International Journal of Mechanical Engineering Education*, *47*(3), 195–209. https://doi.org/10.1177/0306419018754396

Ganley, C. M., & Lubienski, S. T. (2016). Mathematics confidence, interest, and performance: Examining gender patterns and reciprocal relations. *Learning and Individual Differences*, *47*, 182–193. https://doi.org/10.1016/j.lindif.2016.01.002

Hebebci, M. T., & Usta, E. (2022). The Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity, and Critical Thinking Dispositions. *Participatory Educational Research*, *9*(6), 358–379. https://doi.org/10.17275/per.22.143.9.6

Heller, K., & Heller, P. (2010). *Cooperative Problem Solving in Physics A User's Manual Why? What? How? Recognize the Problem What's going on? STEP 1*.

Istiyono, E., Mustakim, S. S., Widihastuti, Suranto, & Mukti, T. S. (2019). Measurement of physics problem-solving skills in female and male students by phystepross. *Jurnal Pendidikan IPA Indonesia*, *8*(2), 170–176. https://doi.org/10.15294/jpii.v8i2.17640

Jewaru, A. A. L., Parno, P., Nasikhudin, N., Kusairi, S., & Latifah, E. (2022). The profile of students' science process skill on thermodynamics topic through authentic PBL with STEM approach and formative assessment. *AIP Conference Proceedings*.

Jewaru, A. A. L., Parno, P., Nasikhudin, N., Kusairi, S., & Latifah, E. (2023). Exploration of students' scientific argumentation ability on thermodynamics through authentic PBL with STEM approach and formative assessment. *AIP Conference Proceedings*, *2569*(1). https://doi.org/10.1088/1742-6596/1013/1/012081

Khan, M., Abid Siddiqui, M., & Malone, K. L. (2022). Scientific attitudes: gender differences, impact on physics scores and choices to study physics at higher levels among pre-college STEM students. *International Journal of Science Education*, *44*(11), 1816–1839.

Liana, Y. R., Linuwih, S., & Sulhadi, S. (2020). The Development of Thermodynamics Law Experiment Media Based on IoT: Laboratory Activities Through Science Problem Solving for Gifted Young Scientists. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *6*(1), 51–64. https://doi.org/10.21009/1.06106

M. Vijaya, B. R., & Buncha, P. (2017). Students Problem-Solving Difficulties and Implications in Physics: An Empirical Study on Influencing Factors. *Journal of Education and Practice*, *8*(14), 59–62. www.iiste.org

Meltzer, D. (2008). Investigating and addressing learning difficulties in thermodynamics. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--3900

Meltzer, D. E. (2002). The relationship

between mathematics preparation and conceptual learning gains in physics: A possible “hidden variable” in diagnostic pretest scores. *American Journal of Physics*, *70*(12), 1259–1268. https://doi.org/10.1119/1.1514215

Meltzer, D. E. (2004). 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*, *72*(11), 1432–1446. https://doi.org/10.1119/1.1789161

Nugent, G., Barker, B., Welch, G., Grandgenett, N., Wu, C. R., & Nelson, C. (2015). A Model of Factors Contributing to STEM Learning and Career Orientation. *International Journal of Science Education*, *37*(7), 1067–1088. https://doi.org/10.1080/09500693.2015.1017863

Priemer, B., Eilerts, K., Filler, A., Pinkwart, N., Rösken-Winter, B., Tiemann, R., & Zu Belzen, A. U. (2020). A framework to foster problem-solving in STEM and computing education. *Research in Science and Technological Education*, *38*(1), 105–130. https://doi.org/10.1080/02635143.2019.1600490

Qotrunnada, N. A. (2022). Analysis of the Difficulties of High School Students in Improving Problem Solving Ability in Physics Learning. *International Journal of Current Educational Research*, *1*(1), 84–101. https://doi.org/10.53621/ijocer.v1i1.141

Sagala, R., Umam, R., Thahir, A., Saregar, A., & Wardani, I. (2019). The effectiveness of stem-based on gender differences: The impact of physics concept understanding. *European Journal of Educational Research*, *8*(3), 753–761. https://doi.org/10.12973/eu-jer.8.3.753

Samsudin, M. A., Zain, A. N., Jamali, S. M., Samsudin, M. A., Zain, A. N., Jamali, S. M., & Ebrahim, N. A. (2019). *Physics Achievement in STEM PjBL : A Gender Study To cite this version : HAL Id : hal-02105683 Physics Achievement in STEM PjBL : A Gender Study*.

Taasoobshirazi, G., & Carr, M. (2008). Gender differences in science: An expertise perspective. *Educational Psychology Review*, *20*(2), 149–169. https://doi.org/10.1007/s10648-007-9067-y

Tan, A. L., Ong, Y. S., Ng, Y. S., & Tan, J. H. J. (2023). STEM Problem Solving: Inquiry, Concepts, and Reasoning. *Science & Education*, *32*(2), 381–397.

Tatar, E., & Oktay, M. (2011). The effectiveness of problem-based learning on teaching the first law of thermodynamics. *Research in Science and Technological Education*, *29*(3), 315–332. https://doi.org/10.1080/02635143.2011.599318

Turns, S. R., & Van Meter, P. N. (2011). Applying knowledge from educational psychology and cognitive science to a first course in thermodynamics. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--17500

Wider, C., & Wider, W. (2023). Effects of Metacognitive Skills on Physics Problem-Solving Skills Among Form Four Secondary School Students. *Journal of Baltic Science Education*, *22*(2), 357–369. https://doi.org/10.33225/jbse/23.22.257