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Unveiling students' conceptions of hydrostatic pressure: a cross-sectional analysis

Mohd Zaidi Amiruddin[1,4], Andi Suhandi[1,2], Nuzulira Janeusse Fratiwi[2], Nurdini[2], Achmad Samsudin[1,2], Bayram Costu[3]
[1]Department of Science Education, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[2]Department of Physics Education, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[3]Department of Science Education, Faculty of Education, Yildiz Technical University, Istanbul, Turkey
[4]Finnish Institute for Educational Research, University of Jyväskylä, Jyväskylä, Finland

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ABSTRACT

This study investigates students' conceptions of hydrostatic pressure, aiming to identify misconceptions (MC) and differences in understanding based on gender. A quantitative method with a cross-sectional study approach was used as the design in this study to explore and measure characteristics involving 186 students with an average age of 17-18 years from three provinces in Indonesia. Data were obtained using a Four-Tier Test to explore students' scientific understanding, MC, and ignorance of hydrostatic pressure. A gender-based differential item functioning (DIF) analysis was also conducted to evaluate any potential bias in concept understanding between male and female students. The results showed that MC about factors affecting hydrostatic pressure were prevalent among students, for example: i) believing that hydrostatic pressure is independent of depth; ii) thinking that fluid type does not affect it; and iii) assuming that gravity has no impact. These findings highlight the need for targeted interventions to address these fundamental MC. DIF analysis showed a significant variation in understanding between genders, where male students tended to show better results on several aspects of scientific conceptions (SCs). These results highlight the necessity for mapping students' initial conceptions before teaching, to enable the development of targeted instructional strategies aimed at addressing MC and improving understanding of critical physics concepts such as hydrostatic pressure.

Corresponding Author:

Andi Suhandi
Department of Science Education, Faculty of Mathematics and Natural Sciences Education
Universitas Pendidikan Indonesia
Dr. Setiabudi Street, No. 229, Isola, Sukasari, Bandung 40154, Indonesia
Email: andi_sh@upi.edu

1. INTRODUCTION

Students' understanding of the concept of hydrostatic pressure often shows a gap between theoretical understanding and daily experience. In line with research by Wijaya *et al.* [1], Saputra *et al.* [2], and Busyairi and Zuhdi [3], who stated that misconceptions (MC) about hydrostatic material are still widely found. This provides information that tracing student MC in physics learning is one of the crucial things to pay further attention to. The importance of hydrostatic pressure in physics makes it one of the main topics that students must understand well because it often appears in various daily life situations, such as in diving, underwater building construction, and laboratory experiments. Thus, knowing the students' conceptions related to hydrostatic pressure is needed so that learning is beneficial and meaningful in school and everyday life. By understanding these conceptions, teachers can better align their instructional strategies with students' needs. This understanding serves as a foundation for determining the most suitable learning models and approaches in the classroom, enabling teachers to design strategies that address MC and strengthen correct understanding.

Students' conceptions are an essential foundation for teachers in determining the suitable learning models and approaches in the classroom [4]. Understanding students' initial conceptions allows teachers to design learning strategies to overcome MC and strengthen correct understanding. Research has shown that MC about hydrostatic pressure are not only common but persist across various educational levels [5]. These MC are often influenced by students' prior experiences and intuitive beliefs, which conflict with scientific explanations. For instance, many students believe that the deeper a liquid is the greater the pressure, but struggle to connect this with the idea that pressure depends on depth regardless of container shape. Such persistent misunderstandings can obstruct meaningful learning if not properly addressed [6]. Addressing these MC is crucial for improving physics education outcomes. According to Lin *et al*. [7], the learning model must be adjusted to the characteristics of students, such as learning style, background knowledge, and cognitive level. The right approach will help create a more meaningful and effective learning experience so students can understand complex concepts such as hydrostatic pressure or another physics concept more easily. Previous studies have used various ways to identify students' conceptions, such as instrument development [8] and media development [9], [10]. The most popular test instruments in identifying conceptions are tier tests such as Two-Tier Test [11], [12], Three-Tier Test [13], [14], Four-Tier Test [15], and Five-Tier Test [16], [17]. However, previous studies generally focused on only one dimension of identifying students' conceptions and were often limited to specific groups or education levels in one region. Previous studies rarely consider variations in MC in large populations such as provinces.

This study investigates the effects of students' conceptions of hydrostatic pressure. While previous research has explored the understanding of hydrostatic pressure in general, it has not specifically addressed how students' conceptions vary across different educational levels and regional backgrounds. The novelty of this study lies in its comprehensive conception test, which identifies and analyzes students' understanding of hydrostatic pressure through a cross-sectional approach involving students from various provinces. This research aims to offer a more holistic overview of students' conceptions, providing specific insights into how MC evolve as students progress through different educational stages, and offering contextual recommendations for teaching this fundamental physics concept. The questions to be answered in this study are: i) How are students' conceptions of hydrostatic pressure? and ii) How is differential item functioning (DIF) based on gender-related to the concept of hydrostatic pressure?

2. METHOD

2.1. Research design

A cross-sectional study with a quantitative method is a research design conducted to explore and measure the characteristics or relationships between particular variables at one specific period without intervention to the research subjects [18], [19]. This design simultaneously collects data from a representative sample of the target population and often uses instruments such as validated questionnaires or surveys to measure the concept of interest. The data collected is numerical and analyzed statistically to identify patterns, trends, or relationships between variables using descriptive, correlation, or regression analysis techniques. The cross-sectional study design is adequate for evaluating and mapping current conditions, such as academic background, learning preferences, social skills, and attitudes toward specific learning methods, so that it can be used to obtain information about the student's conceptions. Therefore, this research is beneficial in the initial study to identify relevant phenomena before proceeding with a more complex longitudinal or experimental design.

2.2. Participants

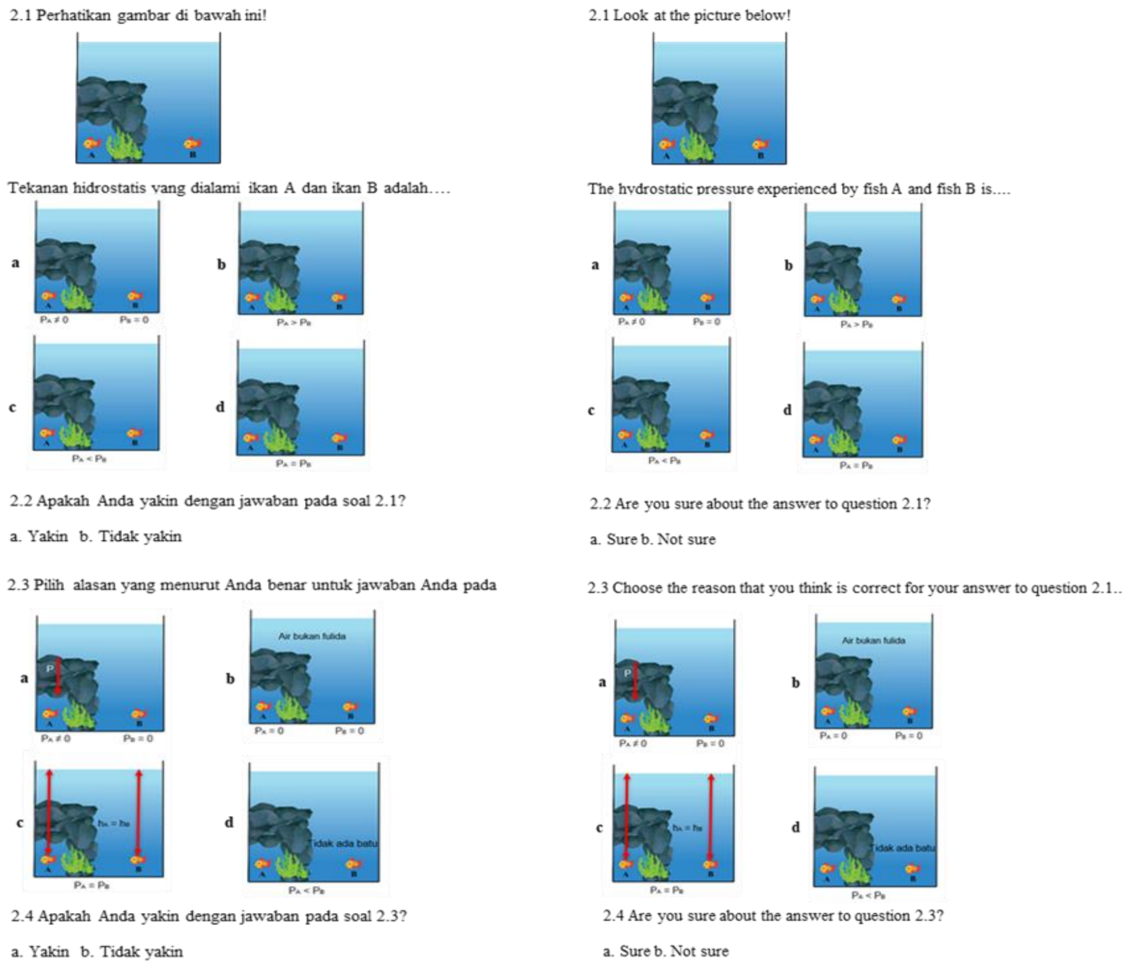
This study involved 186 third-year high school students with an average age of 17-18. Participants came from four schools, four districts, and three provinces in Indonesia. According to Lincare [20], a sample size of 100-200 is considered adequate for obtaining stable parameter estimates in instrument and person evaluation. The selection of participants was based on students who had received fluid material, especially the concept of hydrostatic pressure. Table 1 presents demographic information about the participants, including gender, district location, age, and level of study. The data is structured in two main columns, they are frequency (f), representing the number of participants in each category, and percentage (%), showing the proportion of participants relative to the total of 186 students.

Table 1. Demographic characteristic

Demographic characteristic		Frequency (f)	Percentage (%)
Gender	Male	58	31.18
	Female	128	68.82
District location	Banjarnegara (K)	43	41.40
	Indramayu (S)	32	23.12
	Sukabumi (C)	77	17.20
	Sleman (G)	34	18.28
Age	17-18	186	100

2.3. Data collections

Data collection used the Four-Tier Test to reveal students' conceptions of hydrostatic pressure. The Four-Tier Test was selected as a research instrument because it has been proven to map students' conceptions well. This is evidenced by previous research using the Four-Tier Test on several other concepts [21], [22]. The validity and reliability of the instrument were assessed using the value based on the Rasch Approach. Instrument validity was evaluated through the raw variance explained by measures, which yielded an eigenvalue of 20%, indicating that the validity criteria were met. Meanwhile, the instrument's reliability was measured at 0.83, categorizing it as good. The Four-Tier test concept consists of four levels, namely: i) primary conception; ii) level of confidence; iii) reason; and iv) level of confidence. Tier-1 is the main question about the concept, Tier-2 is the answer to the level of confidence in Tier-1, Tier-3 is the reason for Tier-1, and Tier-4 is the level of confidence in Tier-3. The form of one example of the instrument used is presented in Figure 1. Figure 1(a) is one of the instruments in the form of Indonesian while Figure 1(b) is the result of translation into English.



(a) (b)

Figure 1. Four-Tier Test: (a) Indonesian and (b) English

2.4. Data analysis

The data obtained from students' test results were processed using Microsoft Excel and referred to the scoring rubric adapted from Gurel *et al*. [23]. This rubric classifies students' responses based on the correctness of the answer and their belief in the answer. The categories used in this study include scientific conception (SC), lack of knowledge (LK), MC, and no understanding (NU). The details of the rubric adaptation are presented in Table 2.

Table 2. Four-Tier Test rubrics

Category	Tier-1	Tier-2	Tier-3	Tier-4
SC	Correct	Sure	Correct	Sure
LK	Correct	Sure	Correct	Not sure
	Correct	Not sure	Correct	Sure
	Correct	Not sure	Correct	Not sure
	Correct	Sure	Wrong	Sure
	Correct	Sure	Wrong	Not sure
	Correct	Not sure	Wrong	Sure
	Correct	Not sure	Wrong	Not sure
	Wrong	Sure	Correct	Sure
	Wrong	Sure	Correct	Not sure
	Wrong	Not sure	Correct	Sure
	Wrong	Not sure	Correct	Not sure
MC	Wrong	Sure	Wrong	Sure
NU	Wrong	Sure	Wrong	Not sure
	Wrong	Not sure	Wrong	Sure
	Wrong	Not sure	Wrong	Not sure

3. RESULTS AND DISCUSSION

This study presents two main findings: the categories of students' conceptions of hydrostatic pressure and DIF analysis based on gender. The categories of students' conceptions include SC, LK, MC, and NU incomprehension on the concept of hydrostatic pressure identified through tests and scoring rubrics that have been adjusted. In addition, DIF analysis was conducted to determine whether there were significant differences in the difficulty level of the questions or how male and female students understood the concepts tested. Both results are further discussed in the discussion section to explore further the differences in conception and gender factors that affect learning outcomes on hydrostatic pressure.

3.1. Student's conception of the hydrostatic pressure

Mapping students' conceptions is crucial because it refers to the SCs of experts that occur naturally and are not made up. In this case, the concept measured is hydrostatic pressure in a fluid material. The results of measuring these conceptions are presented in detail in Table 3. The table shows the distribution of students' understanding of the concept of hydrostatic pressure based on two questions (Q1 and Q2) categorized into SC, LK, MC, and NU. In question Q1, 42 students (22.58%) had corrected scientific understanding; in question Q2, the number increased to 73 (39.25%). This shows an increase in students' understanding of the second question. On the other hand, the LK category decreased from 55 students (29.57%) in Q1 to 11 students (5.91%) in Q2, which indicated that fewer students were hesitant or unsure of their answers. However, the MC category remained the most numerous, with 57 students (30.65%) in Q1 and 82 students (44.09%) in Q2. This shows that the MC category still dominates students' conceptions. Meanwhile, the number of students in the NU category decreased from 32 students (17.20%) in Q1 to 20 students (10.75%) in Q2, which showed an overall improvement in understanding. The two questions only differed in question construction, namely in question Q1 in the form of a statement and question Q2 in the form of a picture with a particular explanation. The accumulated distribution of students' conceptions is presented in Figure 2.

3.2. DIF based on gender

To ensure that the item is not biased towards a particular group, a DIF analysis by gender (male and female) was conducted, which is presented in Figure 3. The black line (L) decreases significantly below the zero axis, indicating that the item disadvantages this group. In contrast, the red line (P) increases sharply above zero, indicating that the same item advantages this group. Meanwhile, the green line is between the two groups, which shows the ideal model according to the Rasch model. Figure 3 shows significant differences in how items in the test work for each gender group. The group represented by the red line (P) appears to gain from the items, while the group with the black line (L) shows a disadvantage. This indicates a potential bias in the items that could unfairly affect the results for either group.

Table 3. Distribution of student conceptions

Questions	Category	SC	Students code	f	%
Q1	SC	3	56LC, 59PC, 69PC, 154LC, 124PC, 127PG, 40LS, 68PC, 118PG, 8PK, 11PK, 25PS, 66PC, 98LG, 99LG, 100LG, 120PG, 121PG, 134LG, 137LG, 151PC, 159PC, 162PC, 165PC, 169PK, 170PK, 175PK, 186PK, 1PK, 4PC, 24PS, 30LS, 34PS, 41PS, 70PC, 72PC, 114LC, 122LG, 129LC, 130LC, 132PC, 148LC, 163LC, 172PK, 185LK	42	22.58
	LK	2	5LC, 23KS, 33PS, 45PK, 65PC, 78PC, 147PC, 157PC, 40LS, 68PC, 118PG, 7PC, 10PK, 44PS, 46LK, 93PK, 95PK, 103LG, 106PG, 116PG, 117PG, 119PG, 126PG, 133LG, 135LG, 138LG, 139PG, 140PG, 141PG, 143LK, 155PC, 156LC, 9LK, 15PS, 17PS, 18PS, 31PS, 36PS, 43PK, 49LK, 53LC, 57LC, 71PC, 73PC, 74PC, 76LC, 77PC, 97PC, 128PC, 143LK, 145PC, 178PK, 180LK, 182PK, 183LK	55	29.57
	MC	1	3PK, 22PS, 62PC, 131LG, 42PS, 47PK, 102PC, 123PC, 167PC, 184LK, 29LS, 38PS, 48PK, 50PK, 84PC, 85PC, 86PC, 88PC, 90LC, 91LC, 92PC, 110PG, 115PG, 136LG, 153PC, 164PC, 168PK, 177PK, 12PS, 13PS, 26PS, 32PS, 35LS, 37PS, 39LS, 52PK, 55PC, 58PC, 60LC, 61PC, 75LC, 79LC, 80PC, 81LC, 82LC, 94PK, 96LC, 105LC, 146LC, 149PC, 160LK, 161LC, 166PC, 173PK, 174PK, 179PK, 181LK	57	30.65
	NU	0	19PS, 27PS, 125PC, 171LK,2PK, 51LK, 83PC, 87PC, 89PC, 101PG, 104PG, 107PG, 108PG, 109PG, 111PG, 112PG, 113PG, 144PK, 158LC, 6PK, 14PS, 16PS, 20PS, 21PS, 28LS, 54LC, 63PC, 64PC, 67PC, 150PC, 152PC, 176PK	32	17.20
Q2	SC	3	2PK, 51LK, 83PC, 87PC, 89PC, 101PG, 104PG, 107PG, 108PG, 109PG, 111PG, 112PG, 113PG, 144PK, 158LC, 7PC, 10PK, 44PS, 46LK, 93PK, 95PK, 103LG, 106PG, 116PG, 117PG, 119PG, 126PG, 133LG, 135LG, 138LG, 139PG, 140PG, 141PG, 142LK, 155PC, 156LC, 8PK, 11PK, 25PS, 66PC, 98LG, 99LG, 100LG, 120PG, 121PG, 134LG, 137LG, 151PC, 159PC, 162PC, 165PC, 169PK, 170PK, 175PK, 186PK, 29LS, 38PS, 48PK, 50PK, 84PC, 85PC, 86PC, 88PC, 90LC, 91LC, 92PC, 110PG, 115PG, 136LG, 153PC, 164PC, 168PK, 177PK	73	39.25
	LK	2	40LS, 68PC, 118PG, 124PC, 127PG, 42PS, 47PK, 102PC, 123PC, 167PC, 184LK	11	5.91
	MC	1	6PK, 14PS, 16PS, 20PS, 21PS, 28LS, 54LC, 63PC, 64PC, 67PC, 150PC, 152PC, 176PK, 9LK, 15PS, 17PS, 18PS, 31PS, 36PS, 43PK, 49LK, 53LC, 57LC, 71PC, 73PC, 74PC, 75LC, 77PC, 97PC, 128PC, 143LK, 145PC, 178PK, 180LK, 182PK, 183LK, 1PK, 4PC, 24PS, 30LS, 34PS, 41PS, 70PC, 72PC, 114LC, 122LG, 129LC,130LC, 132PC, 148LC, 163LC, 172PK, 185LK, 12PS, 13PS, 26PS, 32PS, 35LS, 37PS, 39LS, 52PK, 55PC, 58PC, 60LC, 61PC, 75LC, 79LC, 80PC, 81LC, 82LC, 94PK, 96LC, 105LC, 146LC, 149PC, 160LK, 161LC, 166PC, 173PK, 174PK, 179PK, 181LK	82	44.09
	NU	0	19PS, 27PS, 125PC, 171LK, 5LC, 23KS, 33PS, 45PK, 65PC, 78PC, 147PC, 157PC, 56LC, 59PC, 69PC, 154LC, 3PK, 22PS, 62PC, 131LG	20	10.75

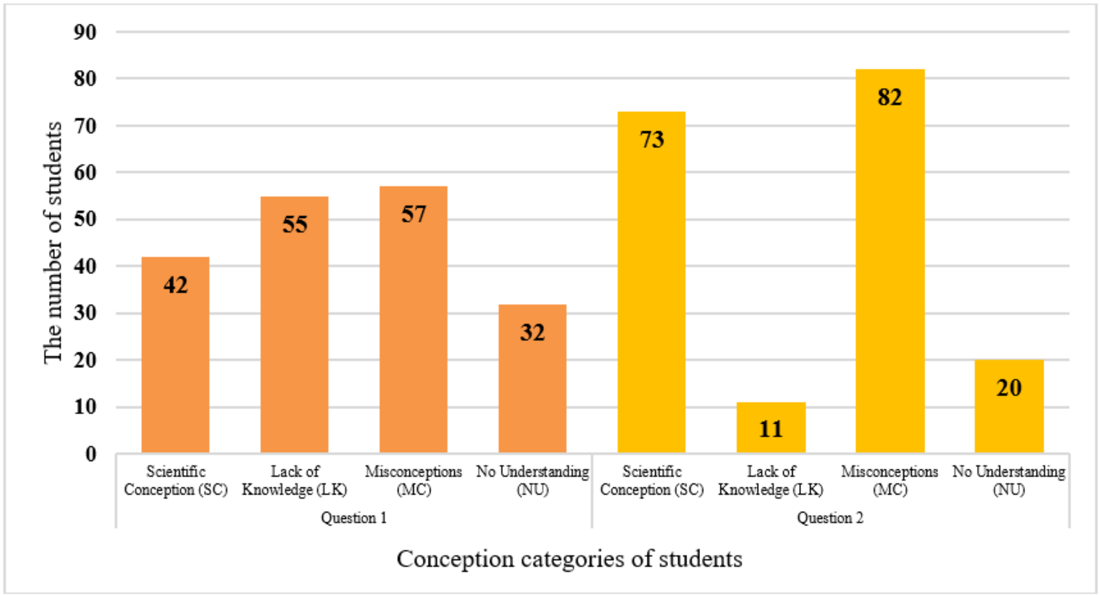


Figure 2. Accumulation of students' conceptions

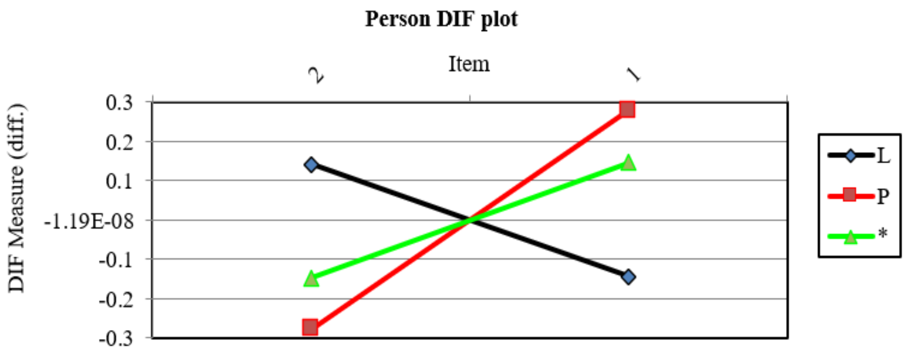


Figure 3. DIF based on gender

3.3. Discussion

The data shown in Table 3 and Figure 2 provide an in-depth insight into students' understanding of the concept of hydrostatic pressure, where different conceptions are categorized into SC, LK, MC, and NU. The misconception category on the concept of hydrostatic pressure still dominates in Q1 and Q2. This is in line with previous research that revealed the concept of hydrostatic pressure [2], [24]. Such MC must be addressed because they affect students' overall conceptual understanding and potentially affect their ability to apply correct scientific concepts in the future. According to Kharrazi *et al*. [25], when MC are not identified and addressed, students may continue to carry them, hindering their understanding of more complex concepts. Thus, revealing conceptions and remediating MC are essential for students' progress.

Students with correct concepts are more likely to apply their scientific knowledge effectively in various contexts, both in the classroom and real-life situations [8], [26]–[29]. In addition, students with scientific understanding are also more confident in facing challenging problems or tasks because they have a strong conceptual basis. The misconception in Q1 was that students chose the option "there is no hydrostatic pressure at the point near the hole" because they misunderstood that hydrostatic pressure depends on whether water flows out or not. The average student's reasoning was "there is no hydrostatic pressure and air pressure at the point near the hole because the system is static and hermetically sealed". The students think that hydrostatic pressure only occurs if there is water movement, so when water does not flow out, hydrostatic pressure is considered non-existent.

Then in Q2 (at the same depth), students chose the answer "fish A experiences hydrostatic pressure while fish B does not experience hydrostatic pressure" on the grounds that "the rocks around fish A are considered to 'remove' hydrostatic pressure from the surrounding water" and "students misunderstand that the presence of objects such as rocks significantly affects hydrostatic pressure". In fact, hydrostatic pressure only depends on three factors: i) the depth of the object in the fluid; ii) the density of the fluid; and iii) the acceleration of gravity. Therefore, since fish A and fish B are at the same depth, they both experience the same hydrostatic pressure, regardless of the presence of rocks around fish A. The rocks do not prevent the fluid from exerting pressure on fish A, as the fluid pressure acts in all directions. By conducting conception mapping, teachers can design appropriate learning for students, especially those lacking concepts.

Exploring further related to the distribution of students' conceptions, a DIF analysis was conducted to see the potential bias. DIF analysis based on gender in Figure 3 highlights gender bias against items. Females with red lines (P) benefit from the items, while males with black lines (L) are disadvantaged. It is crucial to address this bias to make the test results more fair and valid for all students [7], [30]. Previous research has also examined DIF based on gender to anticipate item bias [31], [32]. Using Rasch models can also help detect item bias so that problematic items can be improved or removed to maintain test fairness for both gender groups. In education, the importance of DIF analysis based on gender is not only limited to identifying bias but also plays a role in improving the quality of learning evaluation [3], [33]. Unaddressed item bias can result in incorrect interpretations of students' abilities and can disadvantage certain groups [31], [34]. By performing bias detection through the Rasch model, educators and researchers can make more informed decisions regarding revising or removing problematic items [35], [36]. In addition, adjustments to evaluation instruments based on the results of DIF analysis should also ensure proportional gender distribution.

In this study, female dominated, which could be the reason why DIF measurement favors female. In line with Verdugo-Castro *et al*. [37], Skurka *et al.* [38], gender proportionality is important to consider in the measurement of DIF because it ensures that the items measured have a fair bias among the gender groups being compared. This also has a positive impact on improving the quality of assessment and the validity of test results and ultimately contributes to improved learning and optimal development of student potential [39]–[41].

4. CONCLUSION

The results of this study indicate that MC about hydrostatic pressure remain a significant challenge in physics education. The findings provide convincing evidence that mapping students' conceptions before teaching can help tailor teaching approaches and address MC, ultimately support more effective learning and understand of important physics concepts. Specifically, three factors-depth, fluid density and gravitational acceleration-were at the core of students' MC about hydrostatic pressure. In addition, this study shows that mapping students' conceptions of hydrostatic pressure can identify significant MC, especially in the presence of gender differences in understanding.

Future research could explore the development of alternative teaching materials or learning media that effectively address these MC, with methods that are feasible to implement in diverse classroom settings. This study confirms the importance of mapping students' conceptions of hydrostatic pressure due to the high level of MC. However, further research is needed to confirm the generalizability of these findings, especially regarding gender differences in understanding and the long-term impact of conception mapping on teaching effectiveness.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mohd Zaidi Amiruddin		✓	✓		✓			✓	✓	✓	✓			
Andi Suhandi	✓	✓				✓	✓	✓		✓				
Nuzulira Janeusse Fratiwi				✓		✓	✓	✓	✓			✓		
Nurdini	✓	✓		✓						✓		✓	✓	
Achmad Samsudin	✓	✓			✓	✓	✓		✓					
Bayram Costu		✓		✓	✓					✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors have no known conflict of interest to disclose.

INFORMED CONSENT

The authors have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

This study was conducted in full compliance with ethical guidelines and regulations. All participants provided informed consent, and their anonymity was strictly maintained.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AS], upon reasonable request.

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BIOGRAPHIES OF AUTHORS

Mohd Zaidi Amiruddin is a Doctoral student in the Department of Science Education, Faculty of Mathematics and Natural Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. His research interests are bibliometric analysis, conceptual change, model mental, refutational texts, misconception, and TPACK. He can be contacted at email: mohdzaidi@upi.edu, zaieydiey@gmail.com, or mohd.zai.binamiruddin@jyu.fi.

Andi Suhandi is a lecturer at Department of Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. He is also a professor at the Universitas Pendidikan Indonesia in the field of physics. His current research interests are physics, materials physics, physics education, science education, and teaching and learning such as conception, misconceptions, and conceptual change text. He can be contacted at email: andi_sh@upi.edu.

Nuzulira Janeusse Fratiwi is a lecturer in Department of Physics Education, Faculty of Mathematics and Natural Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. Her current research interests are physics education and cognitive psychology such as identification of conceptions, misconceptions, conceptual change, and development of models, instruments, and media. She can be contacted at email: nuzulira.janeusse.fratiwi@upi.edu.

Nurdini is a lecturer in Department of Physics Education, Faculty of Mathematics and Natural Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. Her research interests include physics education, the development of teaching materials, and studies on learning processes, particularly in the areas of misconceptions, conceptual change, didactic reduction of teaching materials, and science literacy. She can be contacted at email: nurdini@upi.edu.

Achmad Samsudin is a lecturer in Department of Physics Education, Faculty of Mathematics and Natural Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia. His current research interests are physics education, science education, and cognitive psychology such as identification of conceptions, misconceptions, conceptual change, and development of models, instruments, and media. He can be contacted at email: achmadsamsudin@upi.edu.

Bayram Costu is a lecturer at Department of Science Education, Yildiz Technical University, Istanbul, Turkey. He is also a professor at the Yildiz Technical University. His current research interests are teaching and learning, science education, conception, misconceptions, and conceptual change. He can be contacted at email: bayramcostu@gmail.com.