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DEVELOPMENT OF THE 5T-FSMD *(FIVE TIER FLUIDS STATIC MENTAL-MODEL DIAGNOSTIC)* INSTRUMENT TO IDENTIFY STUDENTS' MENTAL MODEL PROFILES

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ABSTRAK

Identifikasi *mental model* peserta didik pada materi fluida statis masih menjadi tantangan karena asesmen konvensional belum mampu mengungkap jawaban, alasan, tingkat keyakinan, dan sumber terbentuknya konsepsi secara komprehensif. Penelitian ini bertujuan mengembangkan instrumen *Five-Tier Fluids Static Mental-Model Diagnostic* (5T-FSMD) yang valid dan reliabel untuk mengidentifikasi profil *mental model* peserta didik pada konsep fluida statis. Penelitian menggunakan metode *Research and Development* (R&D) dengan model pengembangan 4D (*Define, Design, Develop,* dan *Disseminate*). Subjek penelitian melibatkan 198 peserta didik kelas XI SMA di Kota Bandung yang telah mempelajari materi fluida statis. Validitas instrumen dinilai oleh ahli, sedangkan pengujian empiris dilakukan menggunakan analisis *Rasch Model* berbantuan perangkat lunak *Winsteps*. Hasil penelitian menunjukkan bahwa instrumen memiliki validitas isi dan konstruk yang valid dengan koefisien 0,81–0,85. Analisis *Rasch* menghasilkan *Raw Variance Explained* sebesar 38,3%, *person reliability* 0,77, *item reliability* 0,98, dan *Cronbach's Alpha* 0,79. Sebanyak 13 dari 15 butir memenuhi kriteria kesesuaian model. Profil *mental model* didominasi kategori *Synthesis Partial Understanding* (64,88%), diikuti *Scientific Model* (17,04%), *Synthesis Misconception* (12,05%), dan *Initial Model* (6,03%), dengan miskonsepsi tertinggi pada konsep tekanan hidrostatis. Instrumen 5T-FSMD layak digunakan sebagai asesmen diagnostik untuk mengidentifikasi profil *mental model* peserta didik pada materi fluida statis.
Kata Kunci: *Mental Model, Fluida Statis, Five-Tier Diagnostic Test, Rasch Model, Asesmen Diagnostik.*

ABSTRACT

Identifying students' *mental models* of static fluids remains challenging because conventional assessments are unable to comprehensively capture students' answers, reasoning, confidence levels, and the sources of their conceptions. This study aimed to develop a valid and reliable *Five-Tier Fluids Static Mental-Model Diagnostic* (5T-FSMD) instrument to identify students' *mental model* profiles on static fluid concepts. The study employed a *Research and Development* (R&D) approach using the 4D model (*Define, Design, Develop,* and *Disseminate*). The participants were 198 eleventh-grade senior high school students in Bandung who had studied static fluids. The instrument was validated by experts and empirically tested using *Rasch Model* analysis with *Winsteps* software. The results indicated that the instrument

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demonstrated valid content and construct validity, with coefficients ranging from 0.81 to 0.85. The *Rasch* analysis yielded a *Raw Variance Explained* value of 38.3%, *person reliability* of 0.77, *item reliability* of 0.98, and *Cronbach's Alpha* of 0.79. Thirteen of the fifteen items met the model fit criteria. Students' *mental model* profiles were dominated by the *Synthesis Partial Understanding* category (64.88%), followed by the *Scientific Model* (17.04%), *Synthesis Misconception* (12.05%), and *Initial Model* (6.03%), with the highest misconception found in the concept of hydrostatic pressure. Therefore, the 5T-FSMD instrument is suitable as a valid and reliable diagnostic assessment for identifying students' *mental model* profiles on static fluid concepts.
Keywords: *Mental Model, Static Fluid, Five-Tier Diagnostic Test, Rasch Model, Diagnostic Assessment.*

INTRODUCTION

Static fluid is one of the fundamental topics in physics that examines the behavior of fluids in equilibrium, including the concepts of hydrostatic pressure, *Pascal's Law*, and *Archimedes' Principle* (Halliday et al., 2014). Mastery of these concepts is essential because they underpin numerous technological applications encountered in everyday life, such as hydraulic systems, pressure gauges, ships, and dams. Beyond procedural calculation, meaningful physics learning requires students to construct coherent conceptual understanding by integrating newly acquired knowledge with their existing cognitive structures. This integrative process is closely related to students' *mental models*, which function as internal representations that help learners explain scientific phenomena and make sense of situations encountered in real-world contexts (Vosniadou, 2019; Fratiwi et al., 2020). Recent studies also emphasize that the development of appropriate learning environments, including technology-assisted instruction, contributes significantly to strengthening students' *mental models* and conceptual understanding in science learning (Kartika et al., 2025).

Despite its importance, static fluid remains one of the physics topics that students frequently find difficult to understand because it involves abstract reasoning, mathematical representation, and the integration of macroscopic and microscopic perspectives (Suparno, 2013). Difficulties in connecting these multiple representations often lead students to construct *mental models* that are inconsistent with accepted scientific explanations, ultimately resulting in persistent misconceptions (Ozcan & Gercek, 2015). These misconceptions do not merely affect students' ability to answer examination questions but also influence their capacity to interpret physical phenomena correctly and solve contextual problems. Research on conceptual change has shown that misconceptions regarding static fluid concepts require systematic remediation because they tend to persist even after formal instruction if appropriate diagnostic identification is not conducted (Maknun & Marwiah, 2022; Putriardi et al., 2023).

Several empirical studies have reported that misconceptions in static fluid concepts continue to occur across different educational levels. Students frequently assume that buoyant force changes with object depth, hydrostatic pressure depends on fluid volume, or pressure in hydraulic systems is determined by piston area rather than pressure transmission principles (Kafiyani et al., 2019; Suparno, 2013). Similar findings were also reported in recent studies using *five-tier diagnostic tests*, which revealed that misconceptions are often accompanied by inappropriate reasoning patterns and originate from various information sources, including classroom instruction, textbooks, everyday experiences, and personal intuition (Harita et al., 2024). These findings indicate that identifying students' incorrect answers alone is insufficient

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because teachers also need to understand how students develop their conceptions and what factors contribute to the formation of those conceptions.

Unfortunately, assessment practices implemented in many schools still predominantly rely on conventional objective tests that mainly evaluate learning outcomes without providing sufficient information about students' conceptual understanding or reasoning processes. Although the implementation of diagnostic assessment has become increasingly emphasized in the *Merdeka Curriculum*, its application in physics classrooms remains relatively limited (Ardiansyah et al., 2023). Recent developments in educational assessment have encouraged the use of diagnostic instruments capable of simultaneously identifying misconceptions, confidence levels, reasoning patterns, and conceptual sources to support more targeted learning interventions (Okviana et al., 2026). Furthermore, advances in educational measurement, particularly through the application of the *Rasch Model*, have demonstrated considerable potential for producing valid and reliable diagnostic instruments with stronger psychometric characteristics than those evaluated solely through classical test theory (Ibrahim, 2025; Agustinaningsih & Nurjanah, 2025; Azzahra et al., 2024).

On the other hand, static fluid concepts are closely related to various *socio-scientific issues (SSI)* encountered in everyday life, such as the safety of dams, the operation of hydraulic systems in industry, submarine buoyancy, and disaster mitigation associated with water pressure. Understanding these phenomena requires students not only to perform mathematical calculations but also to apply scientific concepts when making reasoned decisions in authentic contexts (Halim et al., 2020). Consequently, evaluating students' *mental models* should extend beyond identifying correct or incorrect answers to examining how conceptual knowledge is organized and applied when addressing contextual scientific problems. Recent studies have also highlighted the importance of developing assessment instruments that measure scientific reasoning and *socio-scientific* competencies to provide a more comprehensive picture of students' conceptual understanding (Agustinaningsih & Nurjanah, 2025; Yuanata et al., 2022).

To obtain comprehensive information regarding students' conceptual understanding, various diagnostic assessment instruments have been developed, ranging from *two-tier* and *three-tier* to *four-tier diagnostic tests*. The development of these instruments reflects continuous efforts to improve the accuracy of identifying misconceptions by incorporating students' reasoning and confidence levels into the assessment process (Fratiwi et al., 2020). Nevertheless, previous studies indicate that *four-tier diagnostic tests* still provide limited information regarding the origins of students' conceptions, making it difficult to explain why misconceptions are formed and maintained. More recently, the development of *five-tier diagnostic tests* has demonstrated greater potential for identifying misconceptions by integrating additional information concerning students' sources of knowledge and conceptual representations (Rokhim et al., 2023; Harita et al., 2024).

Although studies on *five-tier diagnostic tests* have begun to emerge, most have focused primarily on identifying misconceptions in chemistry and selected physics topics rather than comprehensively analyzing students' *mental model* profiles in static fluid concepts (Rokhim et al., 2023; Harita et al., 2024). Furthermore, previous investigations have generally emphasized descriptive categorization of misconceptions without integrating *mental model* classification and rigorous psychometric validation within a single diagnostic framework. Advances in educational measurement recommend that newly developed instruments should satisfy strong validity and reliability criteria through modern measurement approaches, particularly the *Rasch Model*, to ensure accurate interpretation of students' responses (Ibrahim, 2025; Azzahra et al.,

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2024). Therefore, there remains a need for a diagnostic instrument capable of simultaneously identifying students' answers, reasoning, confidence levels, information sources, and *mental model* characteristics using robust psychometric analysis.

Based on these considerations, this study proposes the development of the *Five-Tier Fluids Static Mental-Model Diagnostic (5T-FSMD)* instrument to identify students' *mental model* profiles regarding static fluid concepts. The novelty of this study lies in integrating five diagnostic tiers with *Scientific–Synthesis–Initial (SSI) Mental Model* classification while evaluating the instrument's psychometric quality using the *Rasch Model*. This approach is expected not only to identify misconceptions more comprehensively but also to reveal the cognitive processes and information sources that contribute to students' conceptual construction. Accordingly, this study aims to develop a valid and reliable *5T-FSMD* instrument and to describe students' *mental model* profiles on static fluid concepts as a basis for designing more effective conceptual learning interventions.

RESEARCH METHOD

This study employed a *Research and Development* (R&D) approach using the 4D development model (*Define, Design, Develop,* and *Disseminate*) proposed by Thiagarajan et al. (1974) to develop and validate the *Five-Tier Fluids Static Mental-Model Diagnostic* (5T-FSMD) instrument (Rochmad, 2012; Thiagarajan et al., 1974). During the *Define* stage, curriculum analysis, student characteristics, concept analysis, and a review of relevant literature were conducted to identify essential concepts and common misconceptions related to static fluids. The *Design* stage included preparing the instrument blueprint, developing indicators, constructing 15 five-tier diagnostic items, and designing the scoring guidelines. In the *Develop* stage, the instrument underwent expert validation involving three physics education lecturers and two experienced senior high school physics teachers, followed by revisions based on their recommendations and a limited field trial involving 30 eleventh-grade students who had completed instruction on static fluids. Content and construct validity were evaluated using expert judgment (Aiken, 1985), while the *Disseminate* stage involved administering the finalized instrument to 198 eleventh-grade students from several senior high schools in Bandung, selected through *purposive sampling* because they had studied static fluid concepts (Sugiyono, 2023).

Data were collected using expert validation sheets and students' responses to the 5T-FSMD instrument. Each item consisted of five tiers: answer selection, confidence in the answer, reasoning, confidence in the reasoning, and identification of the source of students' conceptions, enabling comprehensive diagnosis of students' conceptual understanding and *mental models*. The empirical quality of the instrument was analyzed using *Winsteps* version 4.5.3 based on the *Rasch Model* (Bond & Fox, 2015; Linacre, 2022). The analysis included content and construct validity, unidimensionality, item fit statistics, *person reliability*, *item reliability*, *Cronbach's alpha*, and item difficulty, with interpretations based on Sumintono and Widhiarso (2015). Students' responses were subsequently classified into *Sound Understanding, Partial Understanding, Misconception,* and *No Understanding* (Ünal et al., 2010), and then synthesized into four *mental model* categories: *Scientific Model, Synthesis Partial Understanding, Synthesis Misconception,* and *Initial Model*. The instrument was considered feasible when it demonstrated acceptable validity, satisfactory *Rasch* fit indices, reliability coefficients, and the ability to consistently classify students into the predefined *mental model* categories.

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RESULT AND DISCUSSION

Result

Define Stage

The *define* stage was conducted to identify the need for developing a diagnostic instrument capable of revealing students' mental model profiles regarding static fluid concepts. The curriculum analysis indicated that static fluid learning requires students to understand the concepts of Archimedes' principle, Pascal's law, and hydrostatic pressure scientifically rather than merely memorizing formulas. Student analysis and preliminary observations showed that many students experienced conceptual difficulties and misconceptions that could not be adequately identified using conventional assessments. Concept analysis further revealed that existing diagnostic instruments were generally limited to identifying correct and incorrect answers without examining reasoning, confidence level, or the origin of students' conceptions. These findings confirmed the necessity of developing a more comprehensive five-tier diagnostic instrument to identify students' mental models on static fluid concepts.

Design Stage

The *design* stage focused on developing the initial prototype of the Five-Tier Fluids Static Mental-Model Diagnostic (5T-FSMD) instrument based on the needs identified during the *define* stage. An instrument blueprint was prepared by aligning the test specifications with the learning objectives, indicators, and essential concepts of static fluids. The instrument consisted of 15 five-tier diagnostic items, each including answer selection (*Tier I*), confidence in the selected answer (*Tier II*), reasoning selection (*Tier III*), confidence in the selected reasoning (*Tier IV*), and identification of the source of students' conceptions (*Tier V*). In addition, scoring guidelines, expert validation sheets, and mental model classification criteria were developed to ensure that the instrument was ready for validation and empirical testing in the subsequent development stage.

Develop Stage

Content and Construct Validity

The *develop* stage began with evaluating the content and construct validity of the Five-Tier Fluids Static Mental-Model Diagnostic (5T-FSMD) instrument to ensure that each item accurately represented the intended measurement objectives. This validation process was conducted through expert judgment involving five validators, comprising three physics education lecturers and two experienced senior high school physics teachers. The experts assessed the relevance, clarity, appropriateness of item construction, and alignment between the test items and the indicators of static fluid concepts. The results of the content and construct validity analysis using Aiken's V coefficient are presented in Table 1.

Table 1. Content and Construct Validity of the 5T-FSMD Instrument

Parameter	Result	Interpretation
Aiken's V coefficient	0.81–0.85	Valid

As presented in Table 1, the Aiken's V coefficients for all fifteen items ranged from 0.81 to 0.85, indicating that every item met the established validity criterion. These findings demonstrate that the instrument has adequate content and construct validity, reflecting strong agreement among the experts regarding the relevance and appropriateness of the developed

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items. In addition, the validation results confirm that the items are well aligned with the learning objectives, concept indicators, and theoretical framework of static fluid concepts. Therefore, the 5T-FSMD instrument was considered suitable for empirical testing in the subsequent stages of the development process.

Empirical Validity of the Instrument

Following the expert validation process, the empirical quality of the 5T-FSMD instrument was examined using the Rasch measurement model with the support of Winsteps version 4.5.3. The empirical analysis was intended to evaluate whether the developed instrument fulfilled the measurement assumptions required for diagnostic assessment. The first analysis focused on unidimensionality to determine whether the instrument measured a single dominant construct representing students' mental models of static fluid concepts. The results of the unidimensionality analysis are presented in Figure 1.

```
    Table of STANDARDIZED RESIDUAL variance in Eigenvalue units = Item information units
                                              Eigenvalue   Observed   Expected
Total raw variance in observations     =       24.2974 100.0%         100.0%
  Raw variance explained by measures   =        9.2974  38.3%          38.1%
    Raw variance explained by persons  =        2.3200   9.5%           9.5%
    Raw Variance explained by items    =        6.9774  28.7%          28.6%
  Raw unexplained variance (total)     =       15.0000  61.7% 100.0%   61.9%
    Unexplned variance in 1st contrast =        3.6958  15.2%  24.6%
    Unexplned variance in 2nd contrast =        2.6385  10.9%  17.6%
    Unexplned variance in 3rd contrast =        1.7005   7.0%  11.3%
    Unexplned variance in 4th contrast =        1.4208   5.8%   9.5%
    Unexplned variance in 5th contrast =         .9268   3.8%   6.2%
```

Figure 1. Results of the Unidimensionality Test for the 5T-FSMD Instrument

As illustrated in Figure 1, the *Raw Variance Explained by Measures* reached 38.3%, indicating that the instrument successfully measured a common underlying construct. In addition, the *Unexplained Variance in First Contrast* remained within the acceptable range, suggesting that no substantial secondary dimension was detected. These findings indicate that the developed instrument satisfies the unidimensionality assumption required by the Rasch model and is therefore appropriate for subsequent psychometric analyses. The fulfillment of this assumption also supports the interpretation that the instrument consistently measures students' mental models regarding static fluid concepts.

After confirming the unidimensionality of the instrument, the next step involved evaluating the empirical validity of individual items through item fit analysis. This analysis examined the compatibility of each item with the Rasch measurement model using the *Outfit Mean Square (MNSQ)*, *Outfit ZSTD*, and *Point Measure Correlation (Pt Measure Corr)* indices. The evaluation was conducted to identify items that functioned consistently in measuring the intended construct and to determine their suitability for implementation. The results of the item fit analysis are presented in Figure 2.

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ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
13	358	198	.11	.06	1.75	7.97	1.69	6.15	A .22	.50	18.2	28.6	s13
15	365	198	.08	.06	1.71	7.60	1.75	6.59	B .13	.51	27.3	26.5	s15
10	232	198	.65	.07	1.21	2.06	1.34	2.62	C .15	.42	39.9	40.8	s10
9	329	198	.22	.06	1.20	2.43	1.14	1.45	D .49	.49	21.7	28.9	s9
1	488	198	-.41	.07	1.04	.50	1.15	1.39	E .45	.54	37.9	37.2	s1
14	388	198	-.01	.06	1.12	1.54	1.10	1.11	F .40	.52	30.3	28.7	s14
12	429	198	-.17	.06	.89	-1.41	.91	-.93	G .65	.53	24.7	30.8	s12
4	468	198	-.33	.06	.84	-1.92	.78	-2.31	H .63	.54	45.5	35.8	s4
5	162	198	1.06	.09	.83	-1.30	.83	-1.23	g .33	.35	60.1	55.3	s5
2	371	198	.06	.06	.75	-3.46	.73	-3.11	f .63	.51	36.4	29.8	s2
11	245	198	.58	.07	.70	-3.56	.74	-2.48	e .56	.43	37.9	39.5	s11
8	512	198	-.52	.07	.68	-3.77	.72	-2.76	d .72	.54	40.4	39.4	s8
3	529	198	-.60	.07	.70	-3.32	.71	-2.68	c .77	.54	39.4	41.0	s3
6	483	198	-.39	.07	.69	-3.87	.67	-3.55	b .70	.54	38.4	38.3	s6
7	464	198	-.31	.06	.60	-5.32	.59	-4.79	a .71	.54	40.9	35.7	s7
MEAN	388.2	198.0	.00	.07	.98	-.4	.99	-.3			35.9	35.8	
P.SD	106.2	.0	.46	.01	.35	3.9	.35	3.3			10.0	7.1	

Figure 2. Results of the Item Validity Test

As shown in Figure 2, most items satisfied the recommended fit criteria based on the *Outfit MNSQ*, *Outfit ZSTD*, and *Pt Measure Corr* indices. Although several items exhibited slight deviations on one indicator, their overall fit statistics remained within acceptable limits according to Rasch model criteria. Consequently, 13 of the 15 developed items fulfilled the required psychometric standards and were retained for the implementation stage. These findings indicate that the retained items functioned appropriately in measuring students' mental models of static fluid concepts.

Instrument Reliability

Following the empirical validity analysis, the reliability of the developed instrument was evaluated to determine the consistency and stability of the measurement results. Reliability analysis was conducted using three Rasch reliability indices, namely *person reliability*, *item reliability*, and *Cronbach's Alpha*. These indices provide complementary information regarding the consistency of respondents' responses, the stability of item calibration, and the overall internal consistency of the instrument. The results of the reliability analysis are presented in Figure 3.

SUMMARY OF 198 MEASURED Person

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	29.4	15.0	-.04	.24	.99	-.06	.99	-.06
SEM	.7	.0	.04	.00	.03	.08	.03	.08
P.SD	9.5	.0	.56	.04	.40	1.16	.41	1.07
S.SD	9.6	.0	.56	.04	.40	1.17	.41	1.07
MAX.	50.0	15.0	1.33	.41	2.51	3.29	2.47	2.86
MIN.	8.0	15.0	-1.59	.22	.16	-3.39	.28	-3.15

REAL RMSE .27 TRUE SD .49 SEPARATION 1.84 Person RELIABILITY .77
MODEL RMSE .25 TRUE SD .50 SEPARATION 2.01 ~~Person RELIABILITY .80~~
S.E. OF Person MEAN = .04

Person RAW SCORE-TO-MEASURE CORRELATION = .99
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .79 SEM = 4.37
STANDARDIZED (50 ITEM) RELIABILITY = .93

SUMMARY OF 15 MEASURED Item

	TOTAL SCORE	COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	388.2	198.0	.00	.07	.98	-.39	.99	-.30
SEM	28.4	.0	.12	.00	.09	1.05	.09	.89
P.SD	106.2	.0	.46	.01	.35	3.94	.35	3.33
S.SD	109.9	.0	.47	.01	.36	4.07	.37	3.44
MAX.	529.0	198.0	1.06	.09	1.75	7.97	1.75	6.59
MIN.	162.0	198.0	-.60	.06	.60	-5.32	.59	-4.79

REAL RMSE .07 TRUE SD .45 SEPARATION 6.40 Item RELIABILITY .98
MODEL RMSE .07 TRUE SD .45 SEPARATION 6.79 Item RELIABILITY .98
S.E. OF Item MEAN = .12

Figure 3. Results of the 5T-FSMD Instrument Reliability Test

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As presented in Figure 3, the instrument achieved a *person reliability* coefficient of 0.77, indicating good consistency in distinguishing students according to their ability levels. The *item reliability* coefficient reached 0.98, demonstrating excellent stability of the item hierarchy across respondents. Furthermore, the *Cronbach's Alpha* coefficient of 0.79 indicates good internal consistency of the instrument as a whole. Collectively, these findings confirm that the 5T-FSMD instrument provides reliable measurements for identifying students' mental model profiles on static fluid concepts.

Item Difficulty Level

The final psychometric evaluation focused on the difficulty level of the developed items. Item difficulty analysis was performed using Rasch logit measures to examine the distribution of item difficulty across the instrument. This analysis aimed to determine whether the instrument contained items representing various levels of difficulty, thereby enabling the assessment of students with different levels of conceptual understanding. The results of the item difficulty analysis are presented in Figure 4.

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
5	162	198	1.06	.09	.83	-1.30	.83	-1.23	.33	.35	60.1	55.3	s5
10	232	198	.65	.07	1.21	2.06	1.34	2.62	.15	.42	39.9	40.8	s10
11	245	198	.58	.07	.70	-3.56	.74	-2.48	.56	.43	37.9	39.5	s11
9	329	198	.22	.06	1.20	2.43	1.14	1.45	.49	.49	21.7	28.9	s9
13	358	198	.11	.06	1.75	7.97	1.69	6.15	.22	.50	18.2	28.6	s13
15	365	198	.08	.06	1.71	7.60	1.75	6.59	.13	.51	27.3	26.5	s15
2	371	198	.06	.06	.75	-3.46	.73	-3.11	.63	.51	36.4	29.8	s2
14	388	198	-.01	.06	1.12	1.54	1.10	1.11	.40	.52	30.3	28.7	s14
12	429	198	-.17	.06	.89	-1.41	.91	-.93	.65	.53	24.7	30.8	s12
7	464	198	-.31	.06	.60	-5.32	.59	-4.79	.71	.54	40.9	35.7	s7
4	468	198	-.33	.06	.84	-1.92	.78	-2.31	.63	.54	45.5	35.8	s4
6	483	198	-.39	.07	.69	-3.87	.67	-3.55	.70	.54	38.4	38.3	s6
1	488	198	-.41	.07	1.04	.50	1.15	1.39	.45	.54	37.9	37.2	s1
8	512	198	-.52	.07	.68	-3.77	.72	-2.76	.72	.54	40.4	39.4	s8
3	529	198	-.60	.07	.70	-3.32	.71	-2.68	.77	.54	39.4	41.0	s3
MEAN	388.2	198.0	.00	.07	.98	-.4	.99	-.3			35.9	35.8	
P.SD	106.2	.0	.46	.01	.35	3.9	.35	3.3			10.0	7.1	

Figure 4. Results of the Item Difficulty Test

As shown in Figure 4, the item difficulty values ranged from −0.60 to 1.06 logits, indicating that the instrument contained items spanning easy to difficult difficulty levels. Item 5 was identified as the most difficult item, whereas Item 3 represented the easiest item in the instrument. The distribution of item difficulty demonstrates that the developed instrument possesses an appropriate range of difficulty capable of differentiating students with varying levels of conceptual understanding. Overall, these results indicate that the 5T-FSMD instrument satisfies the required psychometric standards in terms of empirical validity, reliability, and item difficulty, making it suitable for implementation in the *disseminate* stage.

Disseminate Stage

Students' Level of Understanding

Following the completion of the *develop* stage, the finalized 5T-FSMD instrument was implemented during the *disseminate* stage to identify students' levels of conceptual understanding regarding static fluid concepts. The instrument was administered to 198

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eleventh-grade senior high school students who had previously studied the topic. Students' responses were classified into five levels of conceptual understanding, namely *Sound Understanding (SU)*, *Partial Positive (PP)*, *Partial Negative (PN)*, *Misconception (MC)*, and *No Understanding (NU)*. The distribution of students' conceptual understanding across the assessed static fluid subconcepts is presented in Table 2.

Table 2. Level of Conceptual Understanding

Subconcept	Question	Number of Conceptual Levels				
		SU	PP	PN	MC	NU
Archimedes' Principle	1	47 (23,74%)	77 (38,89%)	73 (36,87%)	0 (0,00%)	1 (0,51%)
	2	38 (19,19%)	49 (24,75%)	83 (41,92%)	17 (8,59%)	11 (5,56%)
	3	55 (27,78%)	79 (39,90%)	46 (23,23%)	12 (6,06%)	6 (3,03%)
	4	32 (16,16%)	96 (48,48%)	39 (19,70%)	7 (3,54%)	24 (12,12%)
	5	2 (1,01%)	24 (12,12%)	97 (48,99%)	51 (25,76%)	24 (12,12%)
	6	62 (31,31%)	69 (34,85%)	64 (32,32%)	2 (1,01%)	1 (0,51%)
Pascal's Law	7	63 (31,82%)	69 (34,85%)	64 (32,32%)	0 (0,00%)	2 (1,01%)
	8	43 (21,72%)	96 (48,48%)	39 (19,70%)	13 (6,57%)	7 (3,54%)
	9	35 (17,68%)	51 (25,76%)	47 (23,74%)	45 (22,73%)	20 (10,10%)
Hydrostatic Pressure	10	0 (0,00%)	58 (29,29%)	83 (41,92%)	57 (28,79%)	0 (0,00%)
	11	2 (1,01%)	60 (30,30%)	76 (38,38%)	59 (29,80%)	1 (0,51%)
	12	43 (21,72%)	79 (39,90%)	46 (23,23%)	16 (8,08%)	14 (7,07%)
	13	20 (10,10%)	79			

As presented in Table 2, the *Partial Positive* category represented the largest proportion of students, accounting for 33.87% of the responses, followed by the *Partial Negative* category with 31.01%. Only 17.04% of students achieved the *Sound Understanding* category, whereas 12.05% were classified as having misconceptions and 6.03% demonstrated *No Understanding*. Among the three static fluid subconcepts, hydrostatic pressure showed the highest proportion of misconceptions, indicating that this concept remains the most difficult for students to understand scientifically. These findings suggest that although many students have developed partial conceptual understanding, substantial conceptual gaps remain and require further instructional support.

Profile of Students' Mental Models

The results of students' conceptual understanding were subsequently synthesized to determine their overall mental model profiles. This classification integrates students' responses across all five diagnostic tiers to provide a more comprehensive representation of their conceptual structures than conventional conceptual understanding categories alone. Based on the established classification criteria, students' responses were grouped into four mental model categories: *Scientific Model (SM)*, *Synthesis Partial Understanding (Sy-P)*, *Synthesis Misconception (Sy-M)*, and *Initial Model (IM)*. The overall distribution of students' mental model profiles is presented in Figure 5.

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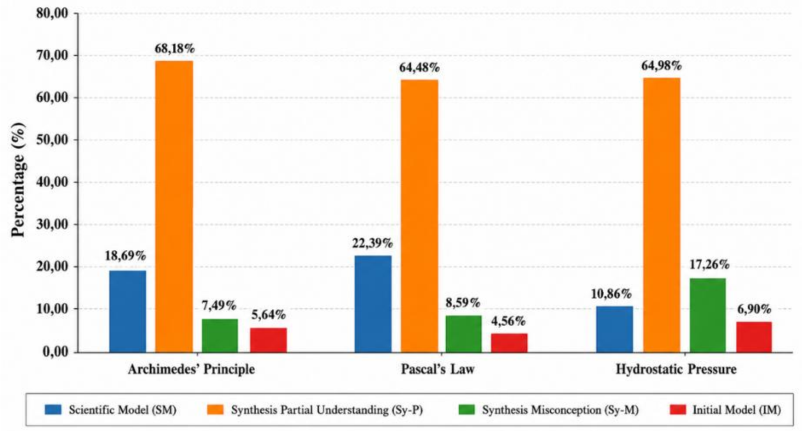

Figure 5. Percentage of Students' Mental Models Regarding Archimedes' Principle, Pascal's Law, and Hydrostatic Pressure

As illustrated in Figure 5, the *Synthesis Partial Understanding* category was the most dominant mental model, representing 64.88% of the students. This was followed by the *Scientific Model* category (17.04%), *Synthesis Misconception* (12.05%), and *Initial Model* (6.03%). The predominance of the *Synthesis Partial Understanding* category indicates that most students have acquired several scientific ideas but have not yet integrated them into complete and coherent mental models of static fluid concepts. These findings demonstrate that the 5T-FSMD instrument is capable of distinguishing different levels of students' mental models and providing detailed diagnostic information to support the improvement of physics instruction.

Mental Model Profiles by Subconcept

Archimedes' Principle

The distribution of students' mental model profiles for the Archimedes' principle subconcept is presented based on the four predetermined mental model categories. As shown by the implementation results, the *Synthesis Partial Understanding* category represented the largest proportion of students, accounting for 67.01% of the total participants. This was followed by the *Scientific Model* category (19.87%), *Synthesis Misconception* (7.49%), and *Initial Model* (5.64%). These results indicate that the majority of students were classified within the *Synthesis Partial Understanding* category, while relatively few students demonstrated a complete scientific mental model for this subconcept.

Pascal's Law

The mental model profiles for the Pascal's law subconcept also showed variation across the four classification categories. The *Synthesis Partial Understanding* category was the most dominant, comprising 61.61% of the students. The remaining students were classified into the *Scientific Model* (23.74%), *Synthesis Misconception* (9.77%), and *Initial Model* (4.86%) categories. Overall, the distribution demonstrates that most students were concentrated in the *Synthesis Partial Understanding* category, whereas the *Scientific Model* category accounted for less than one-quarter of the participants.

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Hydrostatic Pressure

The hydrostatic pressure subconcept exhibited a different distribution of mental model profiles compared with the other assessed subconcepts. Only 10.86% of students were classified in the *Scientific Model* category, representing the lowest proportion among the three subconcepts. The majority of students belonged to the *Synthesis Partial Understanding* category (64.39%), followed by *Synthesis Misconception* (17.76%) and *Initial Model* (6.99%). The results show that hydrostatic pressure had the largest proportion of students classified outside the *Scientific Model* category.

Overall Findings

Overall, the implementation of the 5T-FSMD instrument successfully identified students' mental model profiles across the three static fluid subconcepts. The *Synthesis Partial Understanding* category consistently represented the highest proportion of students in every subconcept that was assessed. In contrast, the *Scientific Model* category accounted for a considerably smaller proportion of students, particularly in the hydrostatic pressure subconcept. These findings demonstrate that the developed instrument was able to differentiate students' mental model profiles and provide detailed diagnostic information regarding their conceptual understanding of static fluid concepts.

Discussion

The findings obtained during the *define* and *design* stages indicate that the development process was initiated through a systematic identification of curriculum requirements, students' characteristics, and common misconceptions regarding static fluid concepts. These preliminary analyses ensured that the diagnostic items represented the essential concepts that should be measured and provided a strong theoretical foundation for constructing the five-tier instrument. The development of the Five-Tier *Fluids Static Mental-Model Diagnostic* (5T-FSMD) instrument demonstrates that diagnostic assessment can provide more comprehensive information than conventional objective tests in identifying students' conceptual understanding. Unlike traditional assessments that only distinguish between correct and incorrect answers, the five-tier format is capable of capturing students' responses, reasoning, confidence levels, and sources of conceptual formation simultaneously. Consequently, the instrument not only identifies misconceptions but also reveals the cognitive structure underlying students' thinking. This finding is consistent with previous studies emphasizing that five-tier diagnostic tests offer richer diagnostic information than three-tier and four-tier instruments because they accommodate multiple dimensions of students' conceptual understanding (Khairunnisa & Sudrajat, 2023; Maharani & Diyana, 2025; Nur et al., 2023).

The *develop* stage focused on evaluating the psychometric quality of the instrument through expert validation and empirical testing using the Rasch Model. The satisfactory validity and reliability indices obtained in this study indicate that the revision process conducted after expert judgment successfully improved the quality of the developed instrument before its implementation. The psychometric evaluation further indicates that the developed instrument possesses appropriate measurement characteristics for educational assessment. The application of the Rasch Model enables a more rigorous evaluation of item quality, respondent consistency, and measurement reliability compared with analyses based solely on classical test theory. Through this approach, each item can be examined individually to determine its contribution to measuring students' mental models, thereby increasing confidence in the interpretation of the

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assessment results. Similar conclusions have been reported in previous studies, which found that Rasch Model analysis provides robust evidence of instrument validity and reliability while supporting the development of high-quality diagnostic assessments in science education (Dharma et al., 2024; Lestari et al., 2022; Mustari et al., 2025).

The implementation conducted during the *disseminate* stage demonstrated that the finalized instrument was capable of identifying variations in students' conceptual understanding after satisfying all psychometric requirements established during the previous development stages. This confirms that the 4D development process produced an assessment instrument that functions effectively in authentic classroom settings. The identification of students' mental model profiles indicates that conceptual understanding of static fluid concepts remains heterogeneous. Differences in students' conceptual structures suggest that learning experiences, prior knowledge, reasoning ability, and the quality of instructional support influence how scientific concepts are constructed. Students with well-developed mental models are generally more capable of connecting theoretical principles with real-life phenomena, whereas those with incomplete conceptual structures tend to rely on fragmented reasoning that often leads to misconceptions. This interpretation is supported by studies demonstrating that conceptual understanding and mental model development are closely associated with scientific reasoning, critical thinking, and meaningful learning experiences (Mansyur et al., 2022; Suparwati et al., 2023; Umam et al., 2026).

The persistence of misconceptions identified through the diagnostic instrument also indicates that conceptual difficulties in static fluid learning remain an important issue in physics education. Previous studies have reported that misconceptions concerning hydrostatic pressure, buoyant force, and fluid equilibrium continue to be experienced by secondary school students despite formal classroom instruction. These findings imply that conventional learning activities are often insufficient to facilitate conceptual change because students tend to retain their initial conceptions when they are not explicitly confronted with scientific explanations. Therefore, the information generated by the 5T-FSMD instrument can serve as a valuable basis for designing targeted remedial instruction that addresses the specific conceptual needs of students. This interpretation is consistent with earlier findings on misconceptions in static fluid learning and the importance of diagnostic assessment as a foundation for effective instructional intervention (Mellu & Langtang, 2023; Ate et al., 2022; Mustari et al., 2025).

The findings also demonstrate that identifying students' mental models provides more meaningful information than merely reporting the proportion of correct and incorrect responses. By combining multiple diagnostic dimensions, the developed instrument enables teachers to distinguish between students who genuinely understand scientific concepts and those who arrive at correct answers through guessing or incomplete reasoning. Such information is particularly valuable for designing instructional strategies that are responsive to students' conceptual needs rather than relying solely on achievement scores. This perspective is consistent with previous studies emphasizing that diagnostic assessment should function not only as an evaluation tool but also as a foundation for improving learning quality through evidence-based instructional decisions (Mustari et al., 2025; Nur et al., 2023; Umam et al., 2026).

From a theoretical perspective, the results reinforce the view that students' mental models are dynamic cognitive structures that evolve through interactions between prior knowledge, classroom experiences, and scientific reasoning. Consequently, misconceptions should not be interpreted merely as incorrect answers but rather as indicators of conceptual

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structures that require systematic reconstruction through meaningful learning experiences. This interpretation explains why students with similar academic backgrounds may demonstrate different conceptual profiles despite receiving the same instructional content. Similar observations have been reported in previous studies, which found that strengthening students' mental models requires instructional approaches that actively engage learners in conceptual reasoning, problem solving, and contextual learning experiences (Suparwati et al., 2023; Ate et al., 2022; Mansyur et al., 2022).

Another important contribution emerging from the 4D development process is that each stage complements the subsequent stage, beginning with problem identification, continuing through instrument construction and psychometric refinement, and ending with implementation in real classroom contexts. This sequential process strengthens the credibility of the developed instrument because its quality is supported not only by theoretical considerations but also by empirical evidence. The present study also contributes to the growing body of research on diagnostic assessment by integrating a five-tier diagnostic test with mental model profiling and psychometric evaluation using the Rasch Model. While previous investigations have primarily focused on identifying misconceptions or validating diagnostic instruments separately, the current approach combines these components into a comprehensive assessment framework capable of generating richer diagnostic information. This integrated approach provides opportunities for teachers and researchers to identify not only students' conceptual difficulties but also the cognitive processes underlying those difficulties. Therefore, the developed instrument has the potential to support more accurate educational decision-making and contribute to the continuous improvement of physics instruction (Khairunnisa & Sudrajat, 2023; Dharma et al., 2024; Lestari et al., 2022).

Overall, the interpretation of the findings across the *define*, *design*, *develop*, and *disseminate* stages confirms that the 4D model provided a systematic framework for producing a valid, reliable, and practically applicable diagnostic instrument. Each stage contributed to improving the quality of the final product, from identifying students’ conceptual needs to verifying its psychometric properties and demonstrating its effectiveness in identifying students’ mental model profiles. Overall, the findings indicate that the Five-Tier *Fluids Static Mental-Model Diagnostic* (5T-FSMD) instrument has considerable potential to support diagnostic assessment in physics learning, particularly in identifying students' conceptual understanding of static fluid concepts. The comprehensive information generated by the instrument can assist teachers in planning targeted remedial instruction, designing conceptual learning activities, and monitoring students' conceptual development more effectively. In addition, the study enriches the literature concerning diagnostic assessment, mental models, and Rasch Model-based instrument development, particularly within the context of physics education. Future research is recommended to implement the instrument across broader educational settings and diverse student populations to further examine its generalizability and effectiveness in supporting conceptual change and improving students' scientific understanding (Maharani & Diyana, 2025; Mellu & Langtang, 2023; Mustari et al., 2025).

CONCLUSION

The findings of this study demonstrate that the developed *Five-Tier Fluids Static Mental-Model Diagnostic* (5T-FSMD) instrument fulfills the criteria of a valid and reliable diagnostic assessment for identifying students’ *mental model* profiles on static fluid concepts. Beyond producing acceptable psychometric characteristics, the instrument provides a more

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comprehensive portrayal of students' conceptual understanding by integrating answers, confidence levels, reasoning, confidence in reasoning, and sources of concept formation within a single diagnostic framework. This capability enables the instrument not only to distinguish between scientific understanding and misconceptions, but also to reveal the cognitive processes underlying students' responses. Consequently, the development of the 5T-FSMD instrument contributes to addressing the existing gap in diagnostic assessment by extending the function of conventional *two-tier*, *three-tier*, and *four-tier* diagnostic tests toward a more holistic evaluation of students' *mental models* in static fluid learning.

The implementation results indicate that most students remain at the *Synthesis Partial Understanding* level, suggesting that they have acquired fundamental scientific ideas but have not yet integrated them into coherent and scientifically consistent *mental models*. The hydrostatic pressure subtopic emerged as the most challenging area, highlighting the need for instructional strategies that emphasize conceptual integration through contextual learning experiences, multiple representations, and diagnostic feedback. Therefore, the 5T-FSMD instrument has strong potential to support teachers in conducting diagnostic assessments, designing targeted remedial instruction, and monitoring students' conceptual development throughout the learning process. Future studies are recommended to validate this instrument across broader educational settings, adapt it to other physics topics, and integrate it into digital assessment platforms to enhance the efficiency and accessibility of diagnostic assessment in science education.

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