

## Competency Profile of Prospective Physics Teachers Regarding Measurement and Uncertainty in Scientific Practice

Awal Mulia Rejeki Tumanggor<sup>1\*</sup>

<sup>1\*</sup> Physics Education Study Program, Manado State University, Tondano, Indonesia

\*Corresponding Author's Email: [awaltumanggor@unima.ac.id](mailto:awaltumanggor@unima.ac.id)

### Abstract

Competence in measurement and uncertainty is an essential foundation for prospective physics teachers; however, it is often not mastered comprehensively. This study aims to analyze the competency profile of prospective physics teachers in the domains of measurement and uncertainty as a foundation for scientific practice. The study employed a mixed-methods case study design involving six prospective physics teachers selected through purposive sampling. Data were collected through structured written tests, think-aloud interviews, and supporting document analysis. The research instruments were validated with an Aiken's V coefficient of 0.872 and demonstrated high inter-rater reliability ( $\kappa = 0.920$ ). The findings revealed varying levels of competence across the procedural (82.5%), conceptual (77.5%), analytical (46.7%), and integrative (32.5%) domains, with systematic misconceptions predominantly identified in uncertainty propagation (83%) and significant figures (83%). Further qualitative analysis indicated that most participants still perceived uncertainty as a technical error rather than an inherent characteristic of the scientific process. This study recommends transforming the physics teacher education curriculum by emphasizing a balance between procedural competence and epistemological understanding, as well as developing instructional strategies to address systematic misconceptions. The implications of this study include developing a multidimensional competency assessment model and instructional intervention designs that foster an authentic understanding of the nature of measurement in science.

**Keywords:** Prospective Physics Teachers, Multidimensional Competence, Measurement Uncertainty.

### Article History:

Received: 28 January 2026

Accepted: 29 July 2026

Published: 20 October 2026

### How to cite:

Tumanggor, A. M. R. (2026). Competency Profile of Prospective Physics Teachers Regarding Measurement and Uncertainty in Scientific Practice. *Jurnal Literasi Pendidikan Fisika*, 7(2), 119-129.

<https://doi.org/10.30872/jlpf.v7i2.6294>

Copyright © 2026 Jurnal Literasi Pendidikan Fisika. This work is licensed under CC BY 4.0.

## INTRODUCTION

The ability to perform accurate measurements and analyze measurement uncertainty constitutes a fundamental competency in scientific practice within physics. From the early stages of physics education, measurement is viewed not merely as a technical activity but also as a representation of scientific thinking that involves understanding the concepts of physical quantities and units, accuracy and precision, measuring instruments and measurement errors, as well as the ability to interpret experimental data. (Mahdiannur, 2024; Schang et al., 2023). In the context of physics education, this competency serves as one of the primary indicators of the quality of prospective physics teachers, as teachers play a crucial role in fostering students' scientific ways of thinking and scientific practices. (Munfaridah et al., 2022; Sivan et al., 2024; Tumanggor, Supahar, Kuswanto, et al., 2020).

Numerous studies have reported that prospective science teachers, including prospective physics teachers, continue to experience difficulties in understanding and applying the concepts of measurement and uncertainty (Geschwind et al., 2024; Unyapoti et al., 2023). Common difficulties

*Competency Profile of...*

include the inability to distinguish between accuracy and precision, errors in determining significant figures, and inaccuracies in reporting measurement results by properly considering random and systematic errors (Gkioka, 2019; Naah & Osei-Himah, 2021; Séré et al., 1993). These findings indicate that measurement has not yet been fully integrated as a comprehensive scientific thinking skill but is still predominantly learned as a procedural activity, detached from the authentic context of scientific practice.

The scientific inquiry paradigm demonstrates how measurement is employed to obtain evidence, analyze uncertainty, and draw conclusions based on empirical data, competencies that prospective teachers need to develop throughout their education (Figueiroa & Moreira, 2014; Siswanto et al., 2023; Tumanggor et al., 2019). These competencies extend beyond conceptual and procedural knowledge to include analytical, evaluative, and reflective abilities that collectively shape a comprehensive scientific competency profile (Kind & Osborne, 2017). Therefore, mapping the competency profile of prospective physics teachers in measurement and uncertainty is essential as a foundation for improving curriculum design and instructional strategies in higher education.

Understanding measurement uncertainty within physics education encompasses a dual dimension. On the one hand, prospective teachers are expected to master this concept as an integral part of physics itself. On the other hand, they must be able to transform such knowledge into effective pedagogical strategies (Strat et al., 2024; Volkwyn et al., 2008). However, previous studies consistently indicate that measurement uncertainty remains a significant challenge for both students and teachers. Sivan et al. (2024) reported that physics education students experienced difficulties in understanding the concept of uncertainty propagation. Similarly, other studies have shown that university students and prospective physics teachers continue to encounter challenges in uncertainty propagation, appropriate implementation of single and repeated measurements, data interpretation, and the reporting of measurement uncertainty (Unyapoti et al., 2023; Wan, 2023).

Empirical observations conducted during the Measurement Instruments course in the Physics Education Study Program at Universitas Negeri Manado revealed that most students still experience difficulties in integrating measurement theory with laboratory practice. Many students are not only unable to operate measuring instruments, such as vernier calipers and micrometer screw gauges, correctly but also lack a comprehensive understanding of the principles of measurement uncertainty. They continue to experience difficulties in determining significant figures and reporting experimental results appropriately. These findings underscore the need for a systematic investigation to identify the actual competency profile of prospective physics teachers regarding measurement and uncertainty. Prospective physics teachers with insufficient mastery of measurement and uncertainty concepts are likely to conduct laboratory instruction that emphasizes procedural routines rather than fostering meaningful conceptual understanding (Gkioka, 2019; Susac et al., 2017).

Based on these conditions, this study specifically aims to map the competency profile of prospective physics teachers in the domains of measurement and uncertainty, encompassing conceptual, procedural, analytical, and integrative competencies. Furthermore, this study seeks to identify the dominant patterns of difficulties and misconceptions related to measurement and uncertainty and to analyze the implications of these findings for the development of physics teacher education.

## METHODS

This study employed a mixed-methods case study design. This design was selected to obtain a comprehensive understanding of the competency profile of prospective physics teachers through the simultaneous integration of quantitative and qualitative data (Creswell & Creswell, 2018). The study focused on an in-depth analysis of participants' competencies in solving problems related to measurement and uncertainty.

The participants consisted of six undergraduate students enrolled in the Physics Education Study Program, who were selected using a purposive sampling technique. The selection criteria included students who were currently taking the Measurement Instruments course and/or had completed instruction on the concepts of measurement and uncertainty. Participants were also selected based on

variations in their academic achievement, as reflected by their cumulative grade point average (GPA), and their willingness to participate throughout all stages of the study.

Data were collected using three instruments: (1) a written test on Measurement Instruments, consisting of four essay questions designed to assess four competency domains, namely conceptual, procedural, analytical, and integrative competencies; (2) a semi-structured think-aloud interview protocol conducted to explore participants' cognitive processes in depth. The interview included guiding questions concerning the rationale behind participants' responses to the written test, their epistemological understanding of measurement uncertainty, and their problem-solving strategies related to measurement tasks; and (3) supporting documents, including lecture notes and laboratory reports, which were analyzed to complement the findings.

The content validity of the research instruments was evaluated by five experts in physics education and physics using Aiken's V index, whereas the reliability of the essay instrument was established through inter-rater reliability using Cohen's Kappa coefficient.

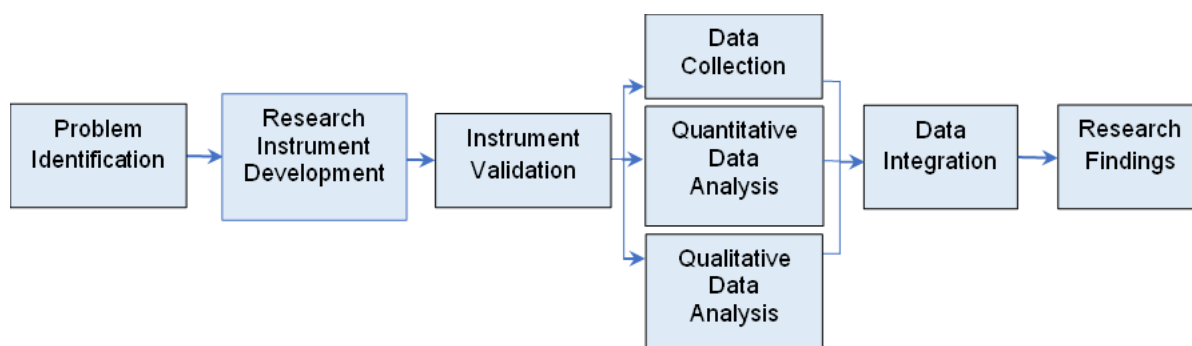


Figure 1. Research procedure diagram

Data analysis was conducted by integrating quantitative and qualitative data. Quantitative data were analyzed using an analytical scoring rubric with a scale ranging from 0 to 4 for each competency indicator, followed by descriptive statistics to calculate the mean, percentage, and standard deviation to describe the competency profile across each domain. The qualitative data were analyzed by first transcribing the interview recordings verbatim, followed by coding, theme identification, theme review, and theme definition using Braun & Clarke (2006) thematic analysis framework. Finally, the quantitative and qualitative findings were integrated to obtain a comprehensive interpretation of the competency profile of prospective physics teachers based on evidence derived from all data sources.

## RESULTS AND DISCUSSION

### Results

Based on the validation process conducted by five experts in physics education and physics using a four-point rating scale, the research instruments demonstrated excellent content validity. Aiken's V yielded an average validity coefficient of 0.872, exceeding the minimum acceptable value of 0.870 according to Aiken's V critical value table at a 5% significance level ( $p < 0.05$ ). Three aspects of the four essay instruments were evaluated, namely item relevance, item construction, and language clarity. All aspects satisfied the minimum validity criterion, with Aiken's V values ranging from 0.867 to 0.933. Regarding instrument reliability, the inter-rater reliability analysis using Cohen's Kappa coefficient produced a value of  $\kappa = 0.920$ . According to the criteria proposed by Landis & Koch (1977), this value indicates almost perfect agreement between the two independent raters. This high level of scoring consistency ensures the objectivity of the assessment process and the reliability of the data obtained.

Based on the analysis of data collected from six prospective physics teachers, varying competency profiles were identified across the four primary domains. Overall, the competency profile exhibited a consistent pattern in which the procedural domain achieved the highest level of mastery (82.5%),

*Competency Profile of...*

followed by the conceptual domain (77.5%), the analytical domain (46.7%), and the integrative domain (32.5%). A detailed overview of the competency profiles is presented in Table 1.

**Table 1.** Competency profile of prospective physics teachers

| Student | Conceptual (%) | Procedural (%) | Analytical (%) | Integrative (%) | Average (%) |
|---------|----------------|----------------|----------------|-----------------|-------------|
| M-01    | 85             | 90             | 40             | 25              | 60          |
| M-02    | 70             | 75             | 55             | 35              | 59          |
| M-03    | 90             | 85             | 30             | 20              | 56          |
| M-04    | 65             | 80             | 60             | 40              | 61          |
| M-05    | 80             | 70             | 45             | 30              | 56          |
| M-06    | 75             | 95             | 50             | 45              | 66          |
| Average | 77,5           | 82,5           | 46,7           | 32,5            | 59,7        |

Beyond the overall competency profile presented in Table 1, an in-depth analysis of each competency indicator revealed more specific patterns of understanding within each domain. Individual analysis showed that M-06 achieved the highest overall competency score (66%), whereas M-03 and M-05 obtained the lowest scores (56%). These differences indicate variations in competency mastery among the participants. Based on the interview findings, M-06 was not only able to apply measurement procedures correctly but also provided conceptual explanations regarding the sources of uncertainty and the rationale for applying uncertainty propagation rules. In contrast, M-03 and M-05 tended to solve problems procedurally without being able to explain the physical meaning underlying each step. These findings indicate that similar learning experiences do not necessarily produce equivalent levels of competency, as they are influenced by differences in conceptual understanding, scientific reasoning ability, and individual knowledge construction.

Within the conceptual domain, most participants (83%, or five out of six prospective physics teachers) were able to correctly explain the concept of the least count and single-measurement uncertainty. However, only 50% were able to accurately distinguish between single-measurement uncertainty and repeated-measurement uncertainty. This finding emerged consistently from both the written test and the interviews, in which most participants experienced difficulties explaining the appropriate context for applying each type of uncertainty.

The procedural domain demonstrated the highest level of achievement, with all participants (100%) correctly reading measurements obtained using vernier calipers and micrometer screw gauges. Nevertheless, the in-depth interviews revealed that only four participants (67%) were able to explain the underlying rationale for assigning single-measurement uncertainty as one-half of the instrument's least count.

The analytical domain presented substantial challenges, with only two participants (33%) correctly calculating repeated-measurement uncertainty. Four participants (67%) made errors in calculating the standard deviation, particularly by failing to apply the  $N - 1$  denominator correctly.

The integrative domain showed the lowest level of achievement. Only one participant (17%) successfully solved problems involving uncertainty propagation, whereas five participants (83%) experienced difficulties applying the uncertainty propagation formula for power functions. This finding indicates limited ability to integrate mathematical concepts into physics applications. Further qualitative analysis identified five systematic patterns of errors, as presented in Table 2.

Conceptual errors related to single and repeated uncertainty (KU1) and errors in standard deviation calculation (KU2) were each identified in 67% of the participants. Errors involving significant figures (AP1) and uncertainty propagation (PPK1) occurred even more frequently, each affecting 83% of the participants. Meanwhile, reporting format errors (PL1) were observed in 50% of the participants. These error patterns were consistently identified through data triangulation involving written tests, interviews, and document analysis, demonstrating consistency across multiple sources of evidence.

**Table 2.** Dominant error pattern of prospective physics teachers

| Error Code                                                                   | Frequency | Data Source                                                                                                                                                                    | Representative Student Response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------------------------------------------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>KU1</b><br>Conceptual misunderstanding of single and repeated uncertainty | 67% (4/6) | <b>Test:</b> Questions 1a and 2b<br><br><b>Interview:</b> Response to the question, "When should single-measurement uncertainty and repeated-measurement uncertainty be used?" | <ul style="list-style-type: none"> <li>• <b>M-03:</b> "Conceptual misunderstanding of single and repeated uncertainty" (incorrect concept)</li> </ul> <p>Correct concept:<br/>Single-measurement uncertainty is applied when a measurement is performed once and is determined by the precision of the measuring instrument, whereas repeated-measurement uncertainty is applied when measurements are repeated and is calculated from the data dispersion (standard deviation). In scientific practice, both types are used to describe the overall accuracy and precision of measurement results.</p> |
| <b>KU2</b><br>Errors in calculating standard deviation                       | 67% (4/6) | <b>Test:</b> Question 2b and 4b<br><b>Document:</b> Statistical Calculation Notes                                                                                              | <ul style="list-style-type: none"> <li>• <b>M-05:</b> calculated the standard deviation using an incorrect formula that omitted the (N - 1) term in the denominator:</li> </ul> $\Delta x = \sqrt{\frac{N \sum x_i^2 - (\sum x_i)^2}{N}}$ <p>Correct formula:</p> $\Delta x = \sqrt{\frac{N \sum x_i^2 - (\sum x_i)^2}{N(N - 1)}}$                                                                                                                                                                                                                                                                      |
| <b>AP1</b><br>Errors in significant figures and units                        | 83% (5/6) | <b>Test:</b> Question 3b (P = I <sup>2</sup> R)<br><br><b>Interview:</b> Explanation of the Rules for Multiplication, Powers, Significant Figures, and Rounding                | <ul style="list-style-type: none"> <li>• <b>M-02:</b> P = I<sup>2</sup> R<br/>P = (2.5)<sup>2</sup> × 12.5 = 78.125 Joule (wrong units)</li> </ul> <p>However, the actual rule of multiplication/exponentiation is that the final result follows the number of significant figures, where:</p> <ul style="list-style-type: none"> <li>✓ I = 2.5 A (2 significant figures);</li> <li>✓ R = 12.5 Ω (3 significant figures)</li> </ul> <p>Therefore, the result is:<br/>P = (2.5)<sup>2</sup> × 12.5 = 78.125 watt → (must have 2 significant figures → becomes 78 Watts)</p>                              |
| <b>PPK1</b><br>Errors in uncertainty propagation                             | 83% (5/6) | <b>Test:</b> Question 2d ( $\rho = \frac{m}{\frac{1}{6}\pi d^3}$ )<br><b>Interview:</b> Explanation of partial derivatives                                                     | <ul style="list-style-type: none"> <li>• <b>M-04:</b> Density uncertainty (error propagation) with the formula:<br/><math display="block">\Delta \rho = \frac{\Delta m}{m} + \frac{\Delta d}{d}</math> <p>However, the actual formula should be used:</p> <math display="block">\frac{\Delta \rho}{\rho} = \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(3 \frac{\Delta d}{d}\right)^2}</math> </li> </ul>                                                                                                                                                                                            |
| <b>PL1</b><br>Errors in reporting measurement results                        | 50% (3/6) | <b>Test:</b> Questions 1b, 2c, 4c<br><br><b>Document:</b> Previous lab report                                                                                                  | <ul style="list-style-type: none"> <li>• <b>M-01:</b> Reports "4.15 ± 0.005" without units and without decimal consistency.</li> </ul> <p>The correct reporting of the measurement result is as follows:</p>                                                                                                                                                                                                                                                                                                                                                                                            |

*Competency Profile of...*

| Error Code | Frequency | Data Source | Representative Student Response                                                                            |
|------------|-----------|-------------|------------------------------------------------------------------------------------------------------------|
|            |           |             | ✓ Metal rod length (Vernier caliper):<br>$l = (l_0 \pm \Delta l) = (77,66 \pm 0,01) \text{ mm}$            |
|            |           |             | ✓ Metal rod thickness (Micrometer screw gauge):<br>$x = (x_0 \pm \Delta x) = (6,560 \pm 0,005) \text{ mm}$ |
|            |           |             | ✓ Ball diameter:<br>$d = (d_0 \pm \Delta d) = (6,25 \pm 0,02) \text{ mm}$                                  |
|            |           |             | ✓ Electric Current:<br>$I = (I_0 \pm \Delta I) = (13,06 \pm 0,09) \text{ mA}$                              |

These findings not only reveal the participants' levels of competency but also identify specific areas requiring instructional intervention. The resulting competency profile provides a comprehensive overview of the strengths and weaknesses of prospective physics teachers in the domains of measurement and uncertainty. This profile may serve as an empirical foundation for improving curriculum design and developing more effective instructional strategies in physics teacher education.

## Discussion

This study successfully revealed a complex and multidimensional competency profile of prospective physics teachers in the domains of measurement and uncertainty. The findings, which demonstrate disparities among procedural competence (82.5%), conceptual competence (77.5%), analytical competence (46.7%), and integrative competence (32.5%), corroborate the findings of Buffler et al., (2008), who reported that measurement instruction in higher education often emphasizes the acquisition of technical skills without simultaneously fostering deep conceptual understanding. This phenomenon is particularly concerning because prospective teachers who possess procedural proficiency but lack conceptual understanding are likely to promote instructional practices that are mechanical and procedure-oriented. This tendency was reflected in the interview with participant M-03, who expressed difficulty in providing an in-depth explanation of the philosophical basis of measurement uncertainty.

The high level of achievement in the procedural domain (82.5%) indicates that most participants had mastered fundamental operational skills, such as reading measuring instruments, identifying the least count, and applying measurement procedures according to established protocols. This condition is likely attributable to the characteristics of laboratory instruction, which tends to emphasize repeated practice in using measuring instruments, thereby enabling students to become familiar with standardized procedures. However, this procedural mastery was not consistently accompanied by the ability to explain the scientific rationale underlying the procedures performed. These findings suggest that the instructional process remains more oriented toward procedural fluency than toward fostering a conceptual understanding of the nature of measurement and measurement uncertainty.

A more detailed analysis of individual test items revealed diverse patterns of understanding among the prospective physics teachers. For Question 1, which assessed both procedural and foundational conceptual competencies, all participants (100%) were able to correctly read measuring instruments, whereas only 67% could explain the epistemological rationale for assigning single-measurement uncertainty. This finding is consistent with the study by Vignal et al. (2023), who examined the concept of measurement uncertainty from an epistemological perspective. They found that university instructors expected students to estimate uncertainty systematically in order to recognize that measurement and calculation results are never perfectly exact. However, because uncertainty was not explicitly addressed in laboratory manuals, students frequently neglected to report it in their experimental results.

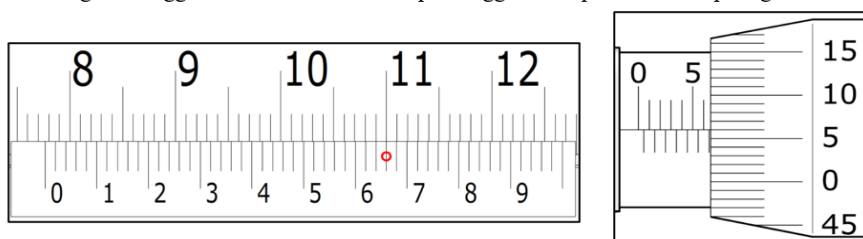
Interpretation of the participants' responses further revealed that they tended to perceive uncertainty as merely a mathematical requirement rather than as a representation of the inherent limitations of the scientific measurement process. This perception is illustrated by participant M-04, who compared measurement uncertainty to manufacturing tolerance in industrial settings, thereby viewing measurement primarily as a technical process for production purposes rather than as an essential component of scientific inquiry.

The lower level of conceptual competence compared with procedural competence indicates that

some participants still experienced difficulties in understanding uncertainty as an inherent characteristic of every measurement process. They tended to perceive uncertainty merely as a computational rule that must be followed rather than as a representation of the intrinsic limitations of scientific observation. This finding suggests that the instructional process places greater emphasis on how to perform measurements than on why uncertainty is an unavoidable component of every measurement result. Consequently, although the participants were capable of carrying out experimental procedures, they had not yet fully developed an understanding of the epistemological foundations underlying measurement and uncertainty.

1. **(Konsep Dasar & Aplikasi)**

Seorang mahasiswa mengukur panjang sebuah batang logam menggunakan jangka sorong dan ketebalan logam menggunakan mikrometer sekrup sehingga mendapatkan hasil seperti gambar berikut



Tuliskan hasil pengukuran tersebut dengan benar beserta satuannya!

- Tentukan ketidakpastian pengukuran tunggal untuk alat ini! (Tentukan Nilai Skala Terkecil (NST) jangka sorong dan mikrometer sekrup). Jelaskan alasan Anda!
- Laporkan hasil pengukuran panjang dan ketebalan batang logam tersebut secara lengkap menurut kaidah pengukuran ilmiah!

**Figure 2.** Question 1, assessing procedural and foundational conceptual competencies

Question 2, which assessed repeated-measurement uncertainty and uncertainty propagation, exhibited the highest level of difficulty. Only 33% of the participants were able to calculate the standard deviation correctly, while only 17% successfully solved uncertainty propagation problems. These findings are consistent with those reported by Palmgren et al. (2025), who identified students' difficulties in integrating mathematical concepts with physics applications. Qualitative analysis of the participants' cognitive processes further revealed an underlying conceptual problem, with the majority of participants (83%) treating uncertainty as an entity separate from the measured value. This misconception was reflected in the think-aloud interview with participant M-05, who regarded uncertainty merely as an additional component appended to the final measurement report.

2. **(Ketidakpastian Pengukuran Berulang)**

Dalam percobaan menentukan massa jenis sebuah bola logam, seorang praktikan mengukur diameter bola ( $d$ ) sebanyak 5 kali dengan mikrometer sekrup. Data yang diperoleh adalah: 6.25 mm, 6.20 mm, 6.30 mm, 6.22 mm, dan 6.28 mm.

- Tentukan nilai rata-rata diameter bola!
- Hitunglah ketidakpastian pengukuran berulang (standar deviasi) dari data tersebut!
- Tuliskan hasil pengukuran diameter secara lengkap!
- Jika massa bola tersebut adalah  $(125.50 \pm 0.05)$  gram, hitunglah massa jenis bola tersebut beserta ketidakpastiannya! (Rumus massa jenis:  $\rho = \frac{m}{\frac{1}{6} \pi d^3}$ )

**Figure 3.** Question 2, assessing repeated measurements and their uncertainty

The relatively low level of analytical competence (46.7%) indicates that the participants encountered considerable difficulties when required to integrate physics concepts with quantitative analysis, such as calculating the standard deviation and interpreting the results of repeated measurements. These difficulties are likely attributable to weak connections between mathematical understanding and the physical meaning of measurement uncertainty. The participants tended to focus on applying formulas without understanding the rationale for selecting particular analytical procedures or interpreting the resulting data. Consequently, analytical competence proved to be substantially more demanding than

merely performing measurement procedures.

Question 3, which assessed significant figures and types of measurement errors, revealed that 83% of the participants made errors in applying the rules of significant figures. This high percentage indicates a limited understanding of the role of significant figures in the scientific communication of measurement results. This finding is consistent with the study by Wan (2023), which emphasized the importance of significant figures, statistical uncertainty, and the standard deviation of measurements as indicators of understanding the nature of scientific practice. A conceptual interpretation of the participants' responses revealed that they regarded the rules of significant figures merely as conventions rather than as representations of measurement precision. This perception was reflected in participant M-02's analogy, in which significant figures were compared to grammatical rules in writing.

### 3. (Analisis Kesalahan & Angka Penting)

Dua kelompok melakukan pengukuran kuat arus listrik yang sama, seperti berikut:

- Kelompok A melaporkan:  $I = (2.5 \pm 0.1) \text{ A}$
  - Kelompok B melaporkan:  $I = (2.48 \pm 0.05) \text{ A}$
- a) Manakah hasil pengukuran yang lebih presisi? Jelaskan!
  - b) Berdasarkan aturan angka penting, hitunglah operasi berikut menggunakan hasil pengukuran Kelompok A  $\rightarrow P = I^2 R$ , di mana  $R = 12.5 \Omega$ .  
Tuliskan hasil akhir P dengan jumlah angka penting yang tepat!
  - c) Jenis kesalahan (*random error* atau *systematic error*) apakah yang mungkin menyebabkan perbedaan hasil antara Kelompok A dan B? Berikan satu contoh penyebabnya!

**Figure 4.** Question 3, assessing significant figures and types of measurement errors

Question 4, which assessed repeated measurements and the reporting of measurement results, showed that 50% of the participants made errors in the reporting format. This finding confirms the study by Volkwyn et al. (2008), which highlighted the importance of scientific communication skills. An epistemological analysis further revealed that these reporting errors were not merely technical mistakes but reflected a lack of understanding of the role of scientific reporting as an integral component of scientific practice. This interpretation is illustrated by participant M-01, who considered the reporting format to be unimportant as long as the numerical result was correct.

### 4. (Analisis Pengukuran Berulang dan Komunikasi Ilmiah)

Seorang guru fisika melakukan percobaan pengukuran kuat arus listrik dalam rangkaian DC menggunakan Multimeter sebanyak lima kali menghasilkan pembacaan 13,1 mA; 13,2 mA; 12,9 mA; 12,8mA dan 13,3 mA.

- a) Tentukan nilai rata-rata pengukuran arus listrik dari data pengukuran tersebut!
- b) Hitunglah ketidakpastian pengukuran berulang (standar deviasi) dari data tersebut!
- c) Tuliskan laporan hasil pengukuran arus listrik secara lengkap serta interpretasikan hasil menurut kaidah ilmiah!

**Figure 5.** Question 4, assessing repeated measurement analysis and the reporting of measurement results

Integrative competence emerged as the lowest-performing domain (32.5%), indicating that most participants were not yet able to connect the concepts of measurement, uncertainty, significant figures, and the reporting of experimental results into a coherent and integrated understanding. This low level of achievement suggests that the participants continued to perceive these concepts as separate topics rather than as interconnected components of scientific practice, making it difficult for them to integrate the concepts when solving authentic scientific problems. In fact, integrative competence is an essential competency for prospective physics teachers because it provides the foundation for explaining the relationships among concepts, experimental procedures, data analysis, and scientific communication to students.

The integration of the findings with the theoretical framework points toward the development of a Pedagogical Content Knowledge (PCK) framework specifically designed for the topics of measurement

and uncertainty. This framework encompasses substantive content knowledge concerning the epistemology of measurement, curriculum knowledge that emphasizes the progressive development of conceptual understanding, and pedagogical knowledge aimed at addressing systematic misconceptions (Iqbal & Zulaiha, 2024; Tumanggor, Supahar, et al., 2020). Furthermore, the identification of systematic error patterns provides empirical support for the development of misconception-based instructional approaches, which emphasize the identification and confrontation of misconceptions as an essential starting point for effective learning.

Overall, this study identified three major patterns of difficulties experienced by prospective physics teachers. First, the participants tended to perceive uncertainty as a mathematical procedure that is separate from the physical meaning of measurement. Second, they experienced difficulties integrating mathematical concepts, such as standard deviation and uncertainty propagation, with the interpretation of experimental results. Third, they had not yet understood the role of significant figures and reporting formats as essential components of scientific communication, instead regarding them merely as writing conventions. Collectively, these patterns indicate that the observed misconceptions extend beyond deficiencies in conceptual knowledge to include an incomplete understanding of the nature of measurement as an integral aspect of the nature of science (NOS).

The theoretical implications of this study include the development of a holistic competency analysis framework for prospective physics teachers, empirical support for the theory emphasizing the balance among multiple competency dimensions, and a foundation for developing topic-specific instructional theories. From a practical perspective, the findings recommend the development of instructional modules that emphasize conceptual and epistemological understanding, the refinement of physics teacher education curricula, and continued research to map and monitor the development of prospective physics teachers' competencies over time.

Although this study is limited by its small sample size and its primary reliance on written assessments, it provides a strong empirical foundation for transforming physics teacher education. Overall, the findings underscore that mastery of measurement and uncertainty concepts reflects a broader understanding of the nature of science. Therefore, efforts to improve physics teacher education should extend beyond procedural instruction toward a paradigm that views physics education as the development of holistic scientific literacy.

## CONCLUSION

Based on the findings and discussion presented in this study, it can be concluded that the competency profile of prospective physics teachers in the domains of measurement and uncertainty is characterized by a complex and multidimensional structure. First, a significant disparity was identified between the relatively high level of procedural competence and the comparatively lower levels of conceptual, analytical, and integrative competencies. Although the prospective physics teachers were able to perform measurements correctly using measuring instruments from a technical perspective, they experienced difficulties in understanding the epistemological foundations underlying measurement procedures. Second, the most challenging aspect for the participants was integrative competence, particularly in applying uncertainty propagation and significant-figure principles within scientific contexts. Third, their understanding of the role of measurement uncertainty within the nature of science (NOS) remained predominantly instrumental, as uncertainty was perceived primarily as a technical error to be minimized rather than as an inherent characteristic of the process of scientific knowledge construction.

This study also revealed that the misconceptions exhibited by the prospective physics teachers were both systematic and consistent across participants. These misconceptions extended beyond deficiencies in conceptual knowledge to encompass epistemological dimensions concerning the understanding of science as a discipline. These findings indicate that current instructional practices tend to emphasize mastery of content knowledge and measurement procedures without sufficiently fostering a deeper understanding of the philosophy and epistemology of science.

### Acknowledgements

The author would like to express sincere appreciation to the Physics Education Study Program at Manado State University for facilitating the research activities. The author also thanks the participating prospective physics teachers for their time, cooperation, and contributions to the data collection process.

### Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

### Funding

This research received no external funding.

### Author Contributions

A.M.R.T. was solely responsible for the conceptualization, methodology, investigation, data curation, formal analysis, interpretation of the findings, and preparation of the original manuscript. The author also undertook the review and editing of the manuscript and approved the final version for publication.

### Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to appropriate confidentiality and ethical considerations.

### Ethics Approval and Consent to Participate

The research was conducted with permission from Manado State University and involved undergraduate students enrolled in the Physics Education Study Program. Although formal ethical approval was not obtained, the research was conducted in accordance with applicable ethical principles for research involving human participants. Participation was voluntary, and informed consent was obtained from the participants before data collection.

### Generative AI Declaration

The author did not use generative artificial intelligence (AI) tools in the preparation of this manuscript.

## REFERENCES

- Braun, V., & Clarke, V. (2006). Qualitative Research in Psychology Using thematic analysis in psychology Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- Buffler, A., Allie, S., & Lubben, F. (2008). Teaching Measurement and Uncertainty the GUM Way. *The Physics Teacher*, 46(9), 539–543. <https://doi.org/10.1119/1.3023655>
- Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (Fifth). Sage Publication, Inc.
- Figueiroa, A., & Moreira, J. A. (2014). Initial teacher training: Contribution to an appropriate use of the experimental work. *American Journal of Educational Research*, 8(2), 629–634. <https://doi.org/10.12691/education-2-8-12>
- Geschwind, G., Vignal, M., Caballero, M. D., & Lewandowski, H. J. (2024). Using a research-based assessment instrument to explore undergraduate students' proficiencies around measurement uncertainty in physics lab contexts. *Physical Review Physics Education Research*, 20(2), 20105. <https://doi.org/10.1103/PhysRevPhysEducRes.20.020105>
- Gkioka, O. (2019). Pre-service physics teachers' difficulties in evaluating experimental evidence. *Egitim ve Bilim*, 44(199), 103–126. <https://doi.org/10.15390/EB.2019.8030>
- Iqbal, N. H. M., & Zulaiha, F. (2024). Profil Pedagogical Content Knowledge Mahasiswa Pendidikan Fisika pada mata Kuliah PPL Berdasarkan kerangka Magnusson. *Jurnal Pendidikan Fisika Dan Sains (JPFS)*, 7(2), 144–151. <https://doi.org/10.1016/B978-0-08-044894-7.00642-4>
- Kind, P., & Osborne, J. (2017). Styles of Scientific Reasoning: A Cultural Rationale for Science Education? *Science Education*, 101(1), 8–31. <https://doi.org/10.1002/sce.21251>
- Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, 33(1), 159–174.
- Mahdiannur, M. A. (2024). Exploring Freshmen's Insight on Physics Measurement Uncertainty: Voices from the General Physics Course. *Jurnal Pendidikan Sains (Jps)*, 12(2), 36.

- <https://doi.org/10.26714/jps.12.2.2024.36-43>
- Munfaridah, N., Avraamidou, L., & Goedhart, M. (2022). Preservice Physics Teachers' Development of Physics Identities: the Role of Multiple Representations. *Research in Science Education*, 52(6), 1699–1715. <https://doi.org/10.1007/s11165-021-10019-5>
- Naah, A. M., & Osei-Himah, V. (2021). Exploring Pre-Service Teachers' Previous Knowledge on Fundamental Physical Quantities of Measurement. *International Journal of Research and Review*, 8(11), 44–54. <https://doi.org/10.52403/ijrr.20211107>
- Palmgren, E., Kokkonen, T., & Bruun, J. (2025). Roles of mathematics in physics education: A systematic review. *Physical Review Physics Education Research*, 21(2), 20602. <https://doi.org/10.1103/www-gwp8>
- Schang, A., Dew, M., Stump, E. M., Holmes, N. G., & Passante, G. (2023). New perspectives on student reasoning about measurement uncertainty: More or better data. *Physical Review Physics Education Research*, 19(2), 20105. <https://doi.org/10.1103/PhysRevPhysEducRes.19.020105>
- Séré, M., Journeaux, R., & Larcher, C. (1993). Learning the statistical analysis of measurement errors. *International Journal of Science Education*, 15(4), 427–438. <https://doi.org/10.1080/0950069930150406>
- Siswanto, J., Suyidno, S., Mahtari, S., Fitriyani, F., Febriani, W., & Sari, E. (2023). The Barriers to Developing Students' Scientific Literacy in Learning Physics of Quantities and Measurements. *Jurnal Pendidikan Sains Indonesia*, 11(2), 206–220. <https://doi.org/10.24815/jpsi.v11i2.27767>
- Sivan, O., Perl-Nussbaum, D., & Yerushalmi, E. (2024). Physics teachers' professional development on measurement uncertainty: A commognitive approach. *Physical Review Physics Education Research*, 20(2), 20146. <https://doi.org/10.1103/PhysRevPhysEducRes.20.020146>
- Strat, T. T. S., Henriksen, E. K., & Jegstad, K. M. (2024). Inquiry-based science education in science teacher education: a systematic review. *Studies in Science Education*, 60(2), 191–249. <https://doi.org/10.1080/03057267.2023.2207148>
- Susac, A., Bubic, A., Martinjak, P., Planinic, M., & Palmovic, M. (2017). Graphical representations of data improve student understanding of measurement and uncertainty: An eye-tracking study. *Physical Review Physics Education Research*, 13(2). <https://doi.org/10.1103/PhysRevPhysEducRes.13.020125>
- Tumanggor, A. M. R., Jumadi, J., Wilujeng, I., & Ringo, E. S. (2019). The Profile of Students' Physics Problem Solving Ability in Optical Instruments. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, 5(1), 29–40. <https://doi.org/10.21009/1.05104>
- Tumanggor, A. M. R., Supahar, Kuswanto, H., & Ringo, E. S. (2020). Using four-tier diagnostic test instruments to detect physics teacher candidates' misconceptions: Case of mechanical wave concepts. *Journal of Physics: Conference Series*, 1440, 012059. <https://doi.org/10.1088/1742-6596/1440/1/012059>
- Tumanggor, A. M. R., Supahar, S., Ringo, E. S., & Harliadi, M. D. (2020). Detecting Students' Misconception in Simple Harmonic Motion Concepts Using Four-Tier Diagnostic Test Instruments. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, 9(1), 21–31. <https://doi.org/10.24042/jipfalbiruni.v9i1.4571>
- Unyapoti, T., Wansudon, S., Inthama, P., & Sujarittam, T. (2023). A Case Study of Pre-service Teachers' Physics Laboratory Skill in Measurement and Uncertainty. *The Asian Conference on Education & International Development 2023 Official Conference Proceedings*, 457–461. <https://doi.org/10.22492/issn.2189-101x.2023.37>
- Vignal, M., Geschwind, G., Pollard, B., Henderson, R., Caballero, M. D., & Lewandowski, H. J. (2023). Survey of physics reasoning on uncertainty concepts in experiments: An assessment of measurement uncertainty for introductory physics labs. *Physical Review Physics Education Research*, 19(2), 12–14. <https://doi.org/10.1103/PhysRevPhysEducRes.19.020139>
- Volkwyn, T. S., Allie, S., Buffler, A., & Lubben, F. (2008). Impact of a conventional introductory laboratory course on the understanding of measurement. *Physical Review Special Topics - Physics Education Research*, 4(1), 1–10. <https://doi.org/10.1103/PhysRevSTPER.4.010108>
- Wan, T. (2023). Investigating student reasoning about measurement uncertainty and ability to draw conclusions from measurement data in inquiry-based university physics labs. *International Journal of Science Education*, 45(3), 223–243. <https://doi.org/10.1080/09500693.2022.2156824>