International Journal of Evaluation and Research in Education (IJERE)
Vol. 14, No. 3, June 2025, pp. 2290~2303
ISSN: 2252-8822, DOI: 10.11591/ijere.v14i3.31864

Evaluating the effectiveness of intervention on professional and pedagogical skills among prospective physics teachers

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Article Info

Article history:

Received Jun 27, 2024
Revised Mar 28, 2025
Accepted Apr 10, 2025

Keywords:

Mann-Whitney test
Pedagogical skills
Professional skills
Teacher competency
Wilcoxon test

ABSTRACT

This study evaluates the effectiveness of a targeted intervention designed to enhance the professional and pedagogical skills of prospective physics teachers, addressing a key gap in teacher education. The research involved an experimental group that received the intervention and a control group that did not. The research subjects in the experimental and control groups were 120 each. To rigorously assess the impact, Whitney and Wilcoxon's statistical tests were employed to compare pretest and posttest outcomes. Additionally, Wright map analysis was used to visualizes kill development. The results revealed a significant improvement in the professional and pedagogical skills of the experimental group compared to the control group, as indicated by Mann-Whitney test ($U=1274.500$, $p<0.05$ and $U=421.500$, $p<0.05$). The Wright map analysis further demonstrated that the experimental group experienced more consistent and substantial gains in pedagogical skills. This study contributes to the field by demonstrating the effectiveness of interventions in improving the skills of prospective physics teachers, offering educational policy recommendations, and filling important gaps in the literature. Moreover, it emphasizes the critical role of ongoing evaluation in the continuous development of teacher training programs. By addressing these areas, this research provides valuable insights that can inform the design and implementation of more effective teacher training strategies.

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1. INTRODUCTION

In Indonesia, teacher professional development continues to face various challenges, including limited access to quality training, lack of incentives, and inadequate facilities. Teacher professional development in Indonesia often focuses on improving pedagogical, personality, professional, and social skills [1]–[3]. In contrast, in developed countries such as Finland, Singapore, and the United States, teacher professional development is carried out systematically and continuously [4]–[6]. Singapore has a robust mentoring system in which junior teachers receive guidance from experienced senior educators [7]. Many schools in the U.S. allocate time and resources for teachers to engage in professional development, including teacher-to-teacher collaboration and school-based initiatives [8], [9].

While Indonesia has implemented efforts to enhance teacher competencies, considerable enhancements are still required regarding accessibility, continuity, and support. Experiences from developed countries show that sustainable investment in teacher professional development is essential to achieve high-quality education and become an inspiration for improving the system in Indonesia [10]. A teacher's pedagogical and professional skills serve as the fundamental basis in education [11]. Pedagogical skills encompass the teacher's ability to design, implement, and evaluate learning processes that are adaptive and responsive to student needs [12]. Professional skills include in-depth knowledge of subject matter, professional ethics, and the ability to innovate in teaching [13]. Without these skills, a teacher may struggle to effectively deliver content, facilitate constructive discussions, and foster critical thinking skills in students.

Physics teacher professional education in Indonesia currently faces major challenges in enhancing teachers' pedagogical and professional competence. Recent studies indicate that many physics teachers in Indonesia struggle with mastering innovative, technology-based learning methods and integrating physics concepts into everyday life [14]. In addition, ever-changing education policies complicate teachers' efforts to adapt to dynamic national curriculum standards [15]. While teacher professional education programs are in place, the lack of ongoing training and periodic performance evaluations has hindered the improvement of teaching quality [16]. Furthermore, there is an urgent need to enhance professional skills, particularly in the use of laboratories and digital learning tools, to support more effective physics instruction in the digital age [17]. Therefore, a comprehensive reform of the teacher professional curriculum along with targeted infrastructure and training improvement is mandatory.

When teachers lack sufficient pedagogical and professional skills, significant challenges can arise. Students may experience difficulties in understanding lesson material, resulting in low learning outcomes and motivation [18], [19]. Therefore, improving teachers' pedagogical and professional competence is imperative to ensure high-quality education and optimal academic achievement for students [20]. The novelty of this research lies in its evaluative approach to assessing the effectiveness of teacher pedagogical and professional competency development programs. This research compares the pedagogical and professional skills of prospective physics teachers who have participated in a professional teacher education program with those who have not [21]. This research is expected to provide a clear picture of the impact of improved teacher competence on the transformation of education in Indonesia. Additionally, the results of this research may serve as a foundation for policymakers in designing more effective and sustainable strategies for teacher professional development.

2. METHOD

This research employed a quantitative approach to evaluate the effectiveness of a pedagogical and professional competency development program for prospective physics teachers. This research involved two groups: an experimental group (n=120) and a control group (n=120). The experimental group comprised prospective physics teachers from two Educational Personnel Education Institutes (LTPK) that offer teachers professional education (PPG) in physics education and participated in a competency development program. On the other hand, the control group consisted of prospective Physics teachers from the same two LTPKs who had not participated in the program. The involvement of control and experimental groups along with random group division was aimed at enhancing the internal validity of the experimental results.

Data collection was carried out using a pretest and posttest to measure the pedagogical and professional skills of prospective teachers. These tests were administered both before and after the implementation of the competency development program. Data collection instruments in this research were pedagogical and professional tests, each comprising 45 items. The instruments demonstrated both validity and reliability, indicating their effectiveness in measuring the intended skills. The validity for the pedagogical test ranged from 0.321 to 0.65,1 while those for the professional test ranged from 0.351 to 0.541. The reliability of the pedagogical test was 0.931, and that of the professional test was 0.891, both falling within the very good category.

The Mann-Whitney test was carried out to determine whether significant differences existed between the two independent groups: the experimental group and control group [22]. Additionally, the Wilcoxon test was utilized to test changes in two paired sets of data, namely pretest and posttest scores in groups, to assess whether there was a significant increase in teachers' pedagogical and professional skills after participating in the development program [23], [24]. Following the Mann-Whitney test and Wilcoxon test, the teacher's abilities in the pretest and posttest were visualized using the Wright map [24]. This visualization tool allows a clear visualization of the enhancement in teachers' pedagogical and professional competence after their participation in the development program [25].

3. RESULTS AND DISCUSSION

3.1. Results

Professional and pedagogical skills are two critical aspects of the teaching profession and play an important role in enhancing the quality of education [26]. Professional competence includes in-depth knowledge of subject matter, the ability to design relevant and engaging learning experiences, and proficiency in using technology and other supporting resources [27]. Teachers with good professional skills can deliver material comprehensively and inspire students to engage in independent learning. Table 1 presents the results of the identification of professional and pedagogical skills.

Table 1. Fit statistics of professional skills and pedagogical skills

	Professional skills		Pedagogical skills	
	Item	Person	Item	Person
Mean	0.00	0.36	0.00	0.82
Measure	-1.89-1.61	-1.62-3.23	-2.73-1.20	-1.09-3.96
SD	0.69	0.97	0.68	0.88
Mean outfit (MnSq)	1.02	-0.04	1.00	0.21
Mean outfit (ZStd)	0.06	1.02	-0.11	0.92
Separation	4.42	3.07	4.17	2.10
Reliability	0.95	0.90	0.95	0.81
Cronbach alpha	0.91		0.81	

The results of the statistical fit test for professional and pedagogical skills, as shown in Table 1, indicate a high level of quality based on various statistical indicators. The average values (mean) for items and persons are 0.00 and 0.36, respectively, reflecting a balanced distribution of values across the measured abilities. The range of measures for items spans from -1.89 to 1.61, while that for persons is from -1.62 to 3.23, demonstrating that this instrument effectively measures wide-scope variations in abilities. The standard deviations for items (0.69) and for persons (0.97) suggests relatively consistent variations in the level of expertise assessed. The mean outfit MnSq index for items is 1.02 and for persons, it is -0.04. The mean outfit ZStd is 0.06 for items and 1.02 for persons, indicating that the data from this instrument is in accordance with the expected model and does not exhibit any significant deviations. Additionally, the separation values for items and persons are 4.42 and 3.07, respectively, demonstrating the instrument's effectiveness in distinguishing between different levels of ability. The high reliability of the instrument is further supported by a Cronbach's alpha value of 0.91 for items and 0.90 for persons, confirming its consistency in accurately measuring the professional skills of prospective physics teachers.

The instrument for measuring the pedagogical skills of prospective physics teachers demonstrates high quality, as indicated by the results of the statistical analysis. The average values (mean) for item and person measures are 0.00 and 0.82, respectively, reflecting a balanced distribution of values with a positive tendency in the measured abilities. The range of items spans from -2.73 to 1.20, while the range for persons is from -1.09 to 3.96, indicating that this instrument effectively measures a broad spectrum of abilities. The standard deviation for items (0.68) and for persons (0.88) suggest consistent variation in the levels of expertise assessed. The mean outfit MnSq index for items is 1.00 and for persons, it is 0.21, while the mean outfit ZStd is -0.11 for items and for 0.92 persons, showing that the data from this instrument aligns well with the expected model and does not exhibit any significant deviations. The high separation values of 4.17 for items and 2.10 for persons demonstrate the instrument’s ability to distinguish between different levels of pedagogical ability effectively. A good level of reliability is indicated by the Cronbach alpha value of 0.81 for items and 0.81 for persons, suggesting that this instrument can be relied on to measure the pedagogical skills of prospective physics teachers accurately and consistently.

3.1.1. Differences on professional skills abilities of prospective physics teachers

To evaluate the effectiveness of the pedagogical and professional competence development program for prospective physics teachers, statistical analyses were performed on the pretest and posttest data from the experimental and control groups [28]. The goal of these analyses was to determine whether there were significant differences in skill improvement following the intervention. The Mann-Whitney test was used to compare the score distributions between two unpaired groups, the experimental and control groups, both before (pretest) and after (posttest) the intervention [29]. The Wilcoxon test was applied to examine changes in pretest and posttest scores within each group, ensuring that any observed improvements in skills were statistically significant [30]. The results of this statistical analysis offer valuable insights into the impact of the competence development program on enhancing the professional skills of prospective physics teachers. The results of this analysis are presented in Tables 2 and 3.

Table 2. Mann-Whitney U test results on professional skills in experimental and control groups (p<0.05)

Test	Experimental group	Control group	U	p
Pretest	-0.17 (-1.52–0.90)	-0.40 (-1.62–0.90)	1347.500	0.017
Posttest	1.65 (0.59–3.23)	0.36 (-0.74–1.62)	183.500	0.000

Table 3. Wilcoxon test results on professional skills in experimental and control groups (p<0.05)

Group	Pretest	Posttest	Z	p
Experimental	-0.17 (-1.52–0.90)	1.65 (0.59–3.23)	-6.736	0.000
Control	-0.40 (-1.62–0.90)	0.36 (-0.74–1.62)	-6.435	0.000

The results of statistical analysis using the Mann-Whitney test, presented in Table 2, indicate a statistically significant difference between the pretest and posttest scores of the prospective physics teachers in the experimental and control groups. In the pretest results, the U value was 1347.500 ($p<0.05$), suggesting a significant difference between the two groups before the intervention. After the intervention, the posttest results revealed a U value of 183.500 ($p<0.05$), indicating that the intervention had a significant impact on improving the professional skills of the experimental group compared to the control group.

The Wilcoxon test results, as shown in Table 3, further supported the finding that there was a significant difference between the pretest and posttest results in both groups. In the experimental group, the Z-value was -6.736 ($p<0.05$), and in the control group, the Z-value was -6.435, with the same p-value. These results indicated that there was a significant improvement in professional skills for prospective physics teachers in both groups after the intervention.

However, the more pronounced significant difference observed in the experimental group indicates that the competency development program was more effective in enhancing the professional skills of prospective physics teachers. The professional skills of the experimental group showed higher gains after the intervention than those of the control group. This underscores the positive impact of the competency development program on participants, highlighting its effectiveness in fostering teacher development. These findings emphasize the importance of sustained competency development programs in improving teaching quality and advancing teacher professionalism.

3.1.2. Professional skills of prospective physics teachers based on control and experimental class

To evaluate the effectiveness of the professional skills development program for prospective physics teachers, an in-depth analysis of the pretest and posttest data was conducted. One of the tools used for this analysis was the Wright map, which visualizes and compares the skill levels of prospective physics teachers before and after the intervention [21]. The Wright map provides a clear depiction of the distribution of abilities both the control group and the experimental group. By mapping the pretest and posttest results of the two groups, significant differences in professional skill attainment between the groups could be identified. This analysis not only helps understand the distribution of abilities but also highlights the changes that occur after the intervention, offering a more comprehensive insight into the effectiveness of the implemented training program [31]. The results of this analysis for both the control and experimental groups are illustrated in Figures 1 and 2.

The Wright map for the control group (Figure 1) illustrates the distribution of pretest and posttest scores for the professional skills of prospective physics teachers. The map shows that both items and people are distributed across a fairly wide range. Most values cluster around the means with some items and persons being less or more frequent than that value. For example, 24COY, which has the highest measure, indicates that only a few prospective physics teachers demonstrated very high professional skills prior to the intervention. In contrast, there are many persons have measure values between -1 and 0, indicating lower to moderate professional skills before the intervention. This distribution reflects significant variation in the skill levels among the control group.

Following the intervention, the Wright map reveals a noticeable shift in person's scores towards higher values, though some remain at lower skill levels. This shows that despite the general improvement in professional skills, some prospective physics teachers did not achieve the expected level of progress. Nevertheless, the overall shift suggests that the intervention had a positive impact, albeit not uniformly across all participants.

The Wright map for the experimental group reveals a more pronounced difference between the pretest and posttest scores compared to the control group. While the item and person measures in the experimental group are also spread across a wide range, there is a higher concentration of scores at the upper end after the intervention. This indicates that a greater number of prospective physics teachers in the experimental group demonstrated significant improvements in professional skills [32].

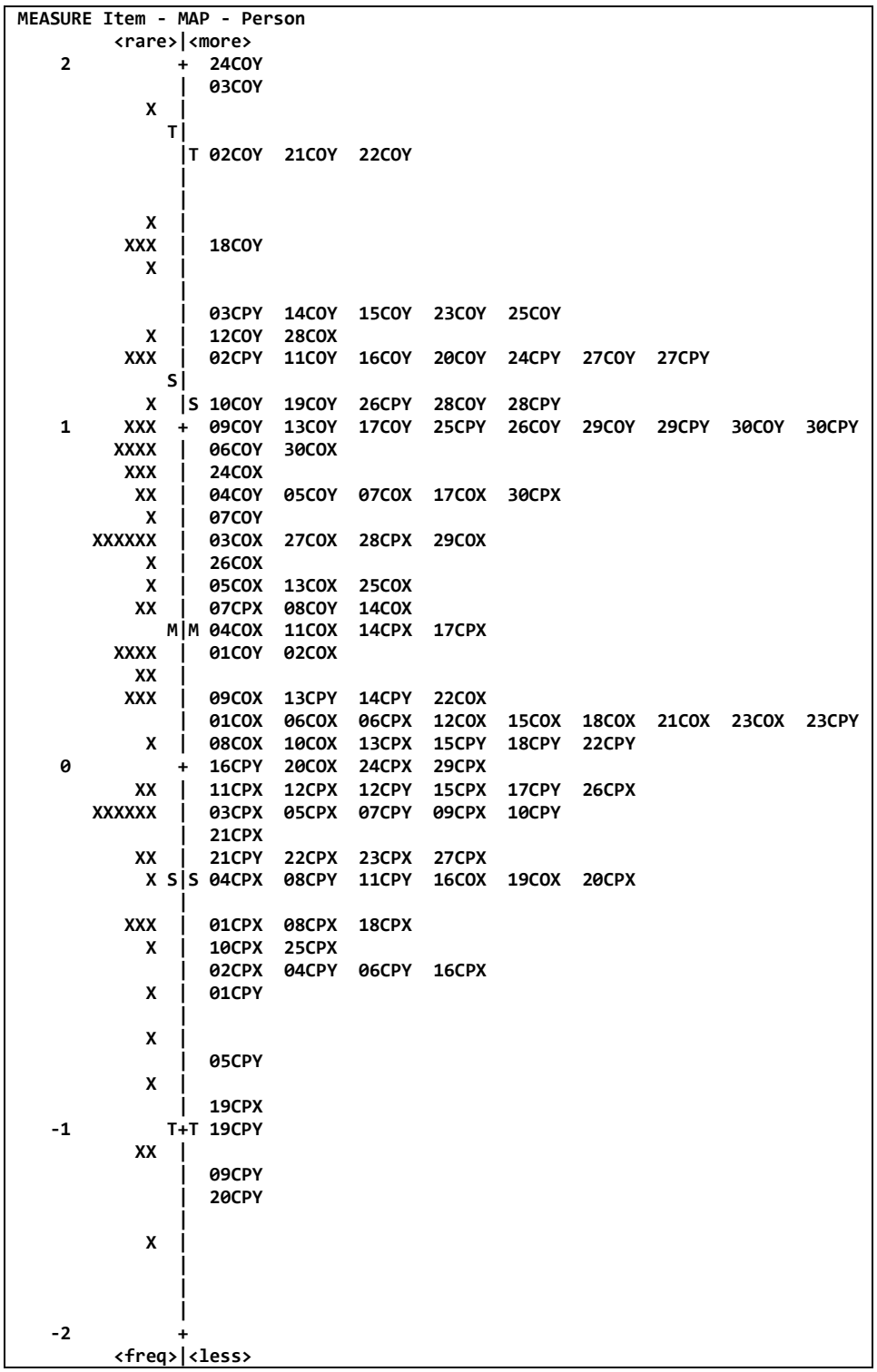

Figure 1. Wright map of pretest and posttest on professional skills of prospective physics teachers in the control group

In the pretest, persons such as 11EOY had high professional skills prior to the intervention. However, after the intervention, a substantial increase in measure values was observed for many persons, with some achieving higher measure values than before, including 29EOX and 30EOY. These results suggest that the competency development program implemented in the experimental group was more effective in enhancing the professional skills of prospective physics teachers compared to the control group [33].

This Wright map indicates that the intervention applied to the experimental group succeeded in improving professional skills significantly better than the control group. The distribution of higher scores and higher person concentration on measures after the intervention in the experimental group demonstrates the effectiveness of the competency development program. The significant difference in score distribution between these two groups reinforces that the approach applied in the experimental group was more successful in enhancing the professional skills of prospective physics teachers.

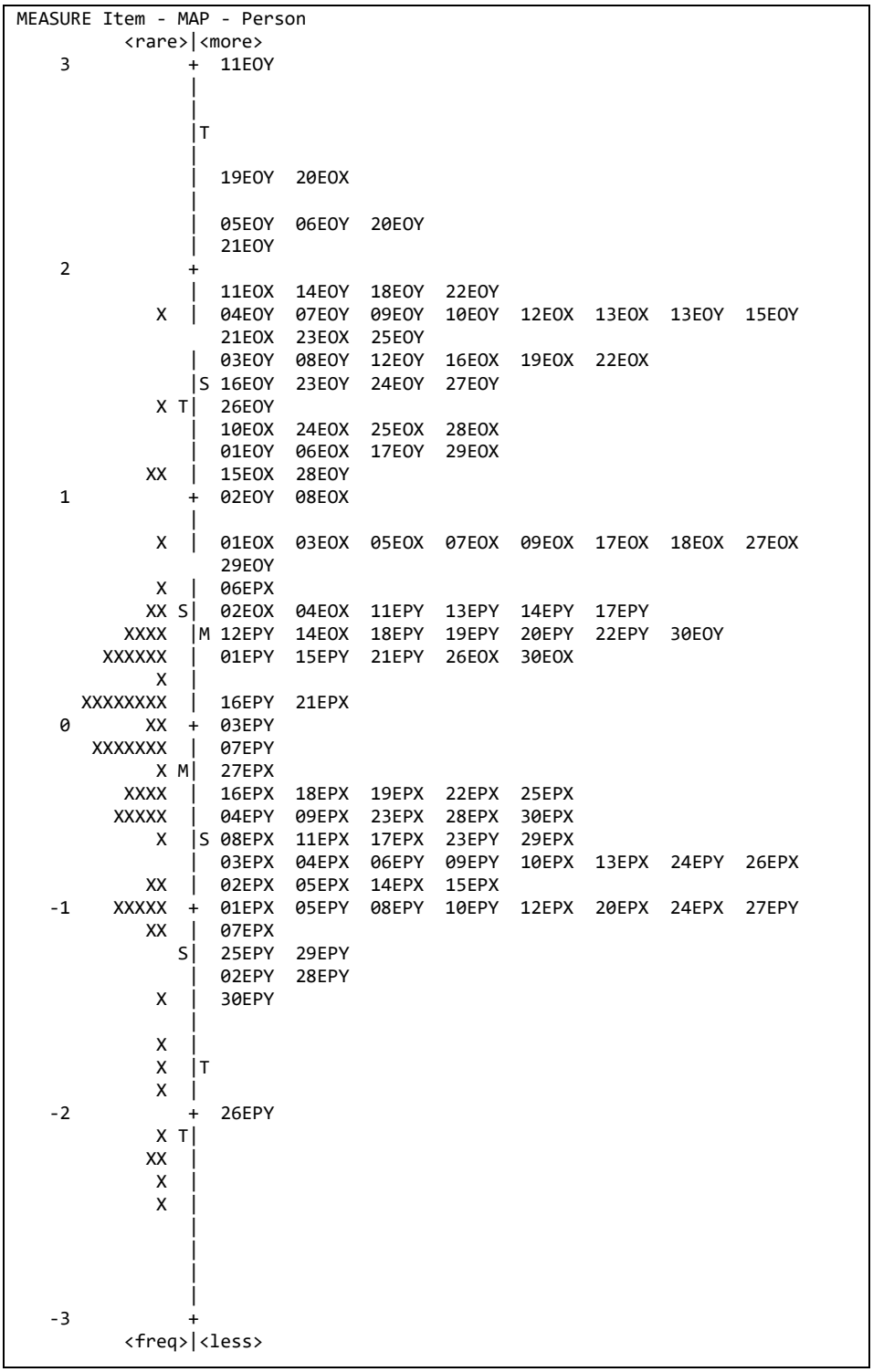

Figure 2. Wright map of pretest and posttest on professional skills of prospective physics teachers in the experimental group

3.1.3. Differences on the pedagogical skills of prospective physics teachers

To understand the effectiveness of the intervention in enhancing the pedagogical skills of prospective physics teachers, statistical analyses were carried out using two non-parametric tests: the Mann-Whitney test and the Wilcoxon test. The Mann-Whitney test was used to compare the distribution of scores between the experimental group, which received the intervention, and the control group, which did not [34]. This test allowed us to determine whether significant differences in pedagogical skills existed between the two groups. On the other hand, the Wilcoxon test was used to assess within-group changes over two time points—before and after the intervention [35]. Together, these analyses provided a comprehensive understanding of the impact of the intervention on the development of pedagogical skills in prospective physics teachers. The results of both statistical tests are presented in Tables 4 and 5.

Table 4. Mann-Whitney U test results on professional skills of the experimental and control group ($p<0.05$)

Test	Experimental group	Control group	U	p
Pretest	0.64 (-0.72–1.68)	0.31 (-1.27–1.14)	1274.500	0.006
Posttest	1.90 (0.27–4.16)	0.48 (-1.29–2.12)	421.500	0.000

Table 5. Wilcoxon test results on professional skills of the experimental and control group ($p<0.05$)

Group	Pretest	Posttest	Z	p
Experimental	0.64 (-0.72–1.68)	1.90 (0.27–4.16)	-6.729	0.000
Control	0.31 (-1.27–1.14)	0.48 (-1.29–2.12)	-2.721	0.006

The results of the Mann-Whitney test (Table 4) reveal a statistically significant difference in the pretest ($U=1274.500$, $p<0.05$) and posttest ($U=421.500$, $p<0.05$) results between the experimental and control groups of prospective physics teachers. The Mann-Whitney test, a non-parametric statistical method for comparing two independent groups, demonstrates that the intervention applied to the experimental group led to a significant improvement in pedagogical skills compared to the control group. The significant results suggest that the targeted intervention had a tangible positive impact on the pedagogical development of the experimental group.

The Wilcoxon test results (Table 5) further support these findings by revealing a significant difference between the pretest and posttest scores for prospective physics teachers in both the experimental group ($Z=-6.729$, $p<0.05$) and the control group ($Z=-2.721$, $p<0.05$). As a non-parametric statistical method, the Wilcoxon test is used to compare two sets of paired data: the pretest and posttest results from the same individual. These results indicate that there was a significant increase in pedagogical skills following the intervention in both groups. However, the increase in the experimental group was higher than in the control group.

Overall, these findings indicate that the pedagogical skills of prospective physics teachers improved after the intervention. The greater gains in the experimental group underscore the effectiveness of the intervention. The higher pedagogical skills in the experimental group indicate that the training program or method was successful in significantly increasing the pedagogical competence of prospective physics teachers. These findings highlight the critical importance of structured and sustainable training programs to elevate the quality of teaching and teacher professionalism [36]. Through appropriate and evidence-based approaches, pedagogical skill development can make a significant positive impact on improving the overall education quality [37].

3.1.4. Pedagogical skills of prospective physics teachers based on control class and experimental class

This mapping of prospective physics teachers' pedagogical skills provides a visual representation of the distribution of participants' abilities and the difficulty of the test items. This facilitates the identification of changes in skill levels before and after the intervention. The Wright Map analysis was conducted on pretest and posttest data on the pedagogical skills of prospective physics teachers in both the control and experimental groups. Interpreting these results is crucial for determining the effectiveness of the implemented interventions. The following detailed analysis of the Wright map for the pretest and posttest of the pedagogical skills provides insights into the improvements or changes in pedagogical abilities after the intervention. Analysis of the pedagogical skills of prospective physics teachers in the control group and experimental group is illustrated in Figures 3 and 4.

Wright Map analysis for pretest and posttest of pedagogical skills in both the control and experimental group offers a detailed visualization of ability distribution and item difficulty. In the Wright Map of the control group, the distribution of persons and items revealed that the pedagogical skills of the

majority of prospective physics varied, with some items proving to be more difficult than others. Persons with codes such as 02COY, 01COY, and 05COY occupied higher positions, indicating better pedagogical skills, while the remaining were dispersed along the scale, with the majority clustered around the middle of the scale (measure=1), signifying moderate variability in pedagogical abilities. This distribution highlights the diversity in pedagogical competency within the control group and suggests that certain test items presented notable difficulties for the prospective physics teachers.

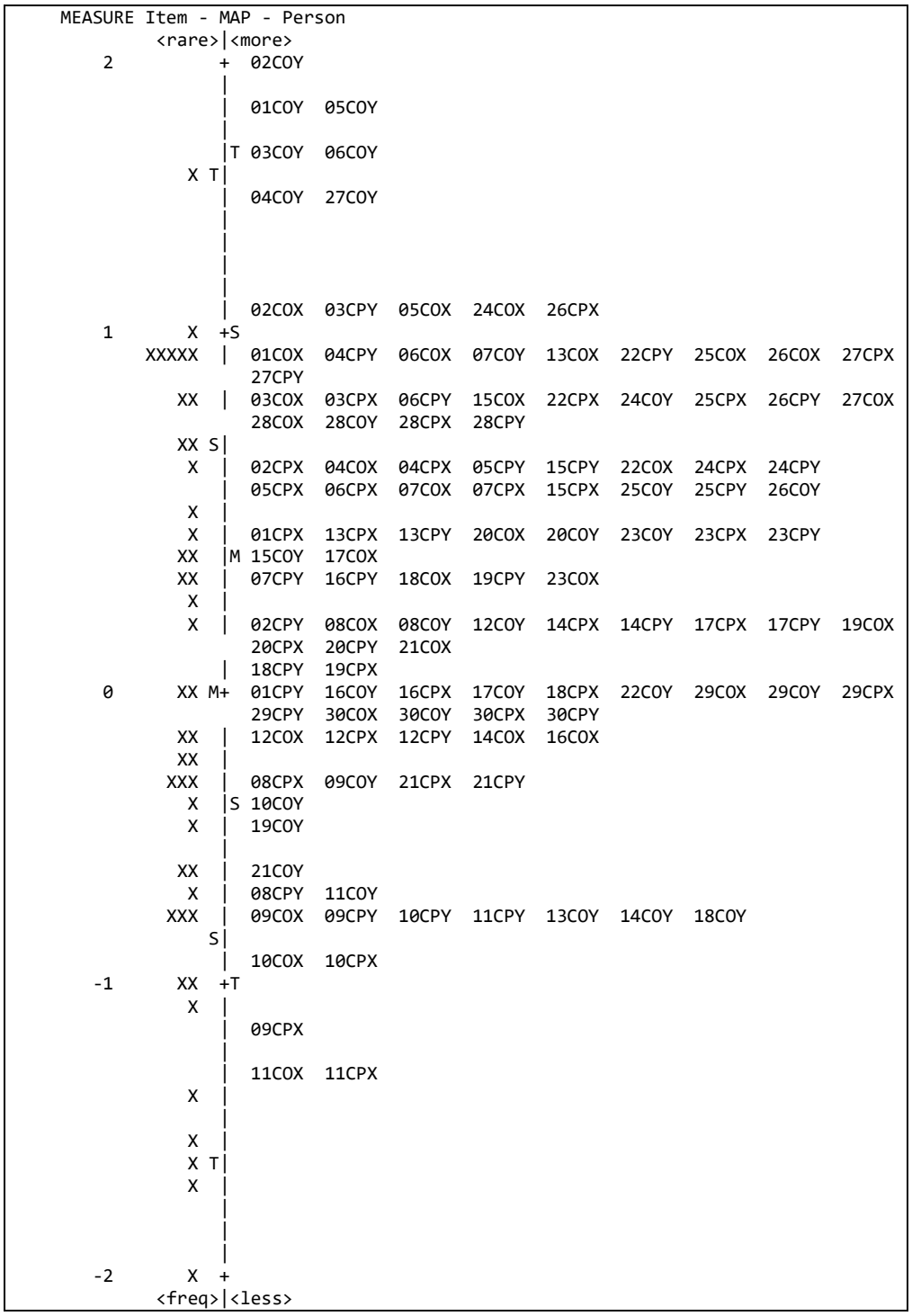

Figure 3. Wright map of pretest and posttest pedagogical skills of prospective physics teachers in the control group

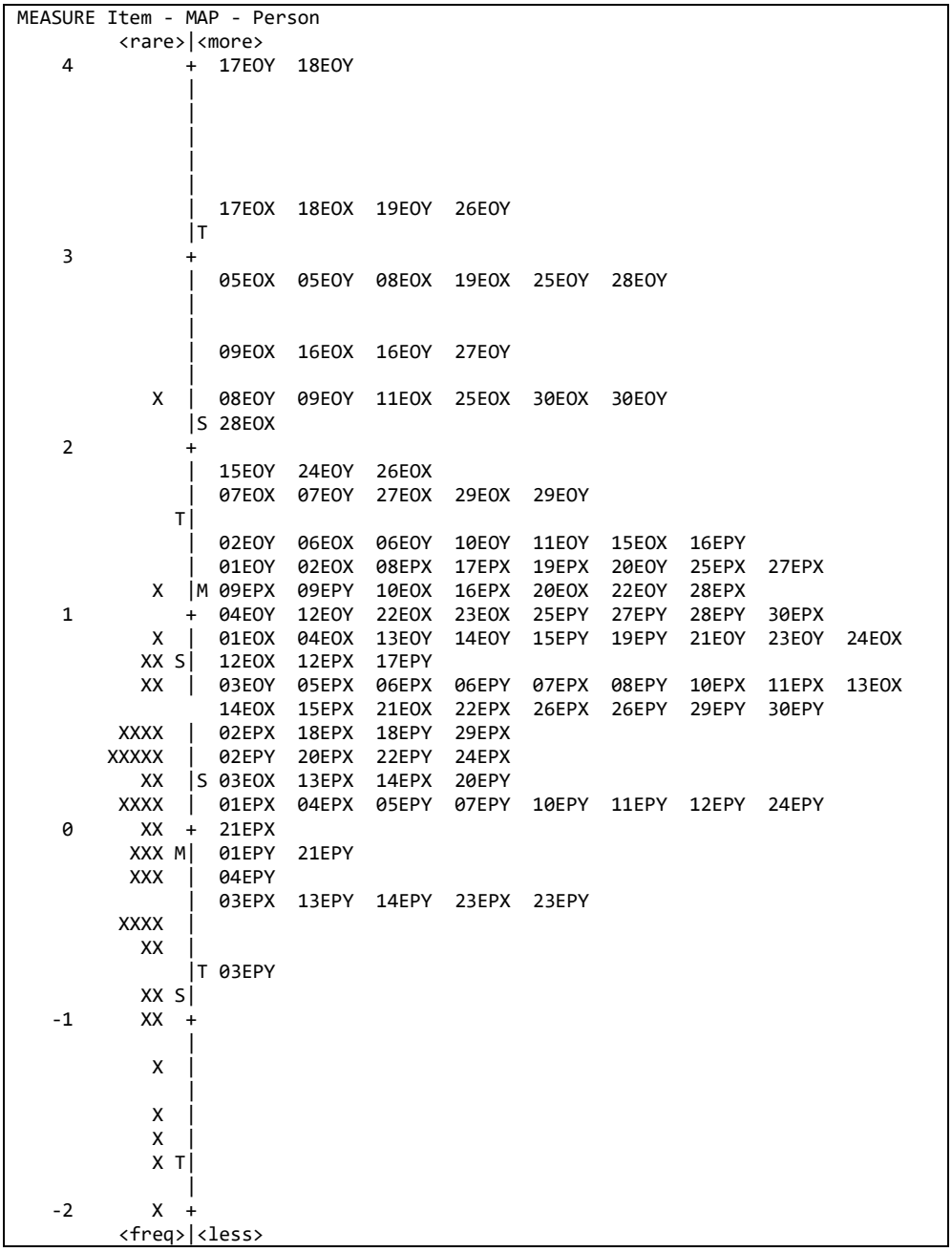

Figure 4. Wright map of pretest and posttest professional skills of prospective physics teachers in the experimental group

In contrast, the distribution of persons and items in the Wright map for experimental group showed a more significant increase in pedagogical skills after the intervention. Persons with codes such as 17EOY, 18EOY, 17EOX, and 18EOX were at higher measures (measure=3 and 4), signifying that the intervention effectively enhanced their pedagogical skills. A larger number of participants from the experimental group are positioned at higher levels compared to those in the control group, indicating the effectiveness of the intervention in improving the pedagogical skills of prospective physics teachers. Although certain items remain challenging for many participants, the overall distribution reflects that persons in the experimental group demonstrated superior abilities compared to those in the control group.

From this analysis, it can be concluded that the intervention applied to the experimental group resulted in significantly greater improvements in the pedagogical skills of prospective physics teachers compared to the control group [38]. The Wright map provides a clear visualization of both ability distribution

and item difficulty, providing valuable insights into the effectiveness of the intervention. These results underscore the importance of structured and evidence-based training programs to enhance the pedagogical quality of prospective physics teachers [39].

3.2. Discussion

3.2.1. Professional skills of prospective physics teachers

Professional skills are an integral aspect for prospective physics teachers, equipping them to meet the demands of their future teaching roles. These skills extend beyond mastery of academic materials, encompassing the ability to adapt to diverse work environments, engage effectively with students, and manage classroom dynamics [40], [41]. A prospective physics teacher with strong professional skills can employ innovative teaching strategies, administer fair and objective assessments, and foster positive relationships with students, colleagues, and other educational stakeholders [42], [43].

Moreover, professional skills are reflected in a teacher's commitment to continuous learning and self-development, whether through additional training, workshops or independent study. This capacity enables prospective teachers to incorporate the latest advancements in education into their teaching practices, ultimately enhancing the quality of student learning experiences [5], [44]. The evaluation aspect of these professional skills often involves the use of measurement tools, such as validity and reliability tests, alongside competency mapping, to assess the degree to which prospective physics teachers have met the required standards in their field [45]. Academically, the professional skills of prospective physics teachers can be assessed using various indicators, such as test scores, peer evaluations, and their ability to design and implement effective learning strategies [46]. The development of these skills is crucial not only for enhancing teaching effectiveness but also for fostering an inclusive learning environment that supports the intellectual and emotional growth of students.

3.2.2. Pedagogical skills of prospective physics teachers

The pedagogical skills of prospective physics teachers serve as the foundation of their ability to effectively convey subject matter, fostering both interest and comprehension among students [47]. Key components of these skills encompass the ability to design a curriculum that aligns with educational standards, select appropriate teaching methods to accommodate students' diverse learning styles, and adeptly utilize educational technology and other resources throughout the learning process [48]. Academically, evaluation of pedagogical skills often involves direct classroom observations, analysis of teaching plans, and portfolio assessments that reflect success in achieving learning objectives [49]. By developing robust pedagogical skills, prospective physics teachers can become effective agents of change, enhancing the quality of education within their communities and preparing future generations with relevant knowledge and skills needed to navigate global challenges [50]–[52].

The assessment of pedagogical skills typically encompasses direct classroom observations, analyses of instructional plans, and evaluations of portfolios that demonstrate success in meeting educational objectives [53]–[55]. By cultivating strong pedagogical skills, prospective physics teachers can serve as effective agents of change in improving the quality of education in their communities and equipping future generations with knowledge and skills relevant to address global challenges [56]–[58].

4. CONCLUSION

This study demonstrated a significant difference between the pretest and posttest results for both experimental and control groups, highlighting the effectiveness of the intervention in enhancing the teaching preparation of prospective physics teachers. The Wright's map analysis of pedagogical skills indicated that the experimental group experienced a more regular and significant increase than the control group, suggesting that the intervention program had a positive and consistent impact on the development of teaching skills. This study contributes to the existing literature on the development of prospective physics teachers by showing that a specifically designed intervention program can significantly improve pedagogical skills. Additionally, the application of Wright map analysis—an approach that is relatively rare in educational research in Indonesia— serves as a tool for deeper evaluation of teaching skill development.

Based on these findings, it is recommended that educational practitioners consider implementing similar intervention programs to enhance the quality of teacher preparation across various regions. This program can serve as a model for developing pedagogical skills among prospective physics teachers in Indonesia. In addition, practitioners should continuously evaluate the program's effectiveness, allowing for necessary adaptations and improvements that align with local needs and evolving global challenges. Further research is needed to evaluate the program's success on a national scale, considering the limited number of research subjects that do not fully represent all regions of Indonesia. Therefore, this study not only provides novel insights into improving teaching quality, but also encourages further discussion regarding the implementation of broader intervention programs.

ACKNOWLEDGMENTS

We would like to express my deepest gratitude to my esteemed mentors, Prof. Dr. apt. Any Guntarti, M.Si. and Prof. Dr. Rully Charitas Indra Prahmana, S.Si., M.Pd., for their invaluable guidance and support in the writing of this scientific article. Their expertise, insightful feedback, and encouragement have greatly contributed to the development and refinement of this work.

FUNDING INFORMATION

We would like to express our gratitude toward Universitas Ahmad Dahlan for their support and funding of this work under the supported professorship candidate research grant 2024 (U7/405/Und-UAD/V/2024).

AUTHOR CONTRIBUTIONS STATEMENT

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

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

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this article.

INFORMED CONSENT

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

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The dataset can be obtained by requesting to the authors.

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