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Comparative Analysis of Fundamental Physics Laboratory Skills Among First-Semester Students in Physics, Chemistry, and Biology Education Programs

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Abstract: This comparative study evaluates the practical laboratory skills of first-semester students in Physics, Chemistry, and Biology Education programs at PMIPA FKIP Universitas Mataram. The research highlights significant variations in skill acquisition, with students in the Physics group (Fis A) demonstrating notably higher proficiency levels compared to students in the Biology (Bio A) and Chemistry (Kim C) groups. The findings underscore the importance of tailored instructional strategies and curriculum enhancements to optimize laboratory instruction and foster skill development across diverse scientific disciplines. By offering evidence-based insights into the effectiveness of laboratory instruction in physics, chemistry, and biology, this study contributes valuable information to the discourse on science education, providing essential guidance for educators to enhance student outcomes in science education programs at PMIPA FKIP Universitas Mataram.

Keywords: Laboratory skills, science education, first-semester students, physics education, chemistry education, biology education, skill assessment, practical skills, comparative analysis

INTRODUCTION

The significance of practical laboratory work in science education has been extensively documented in the literature. According to Singer et al. (2018), laboratory experiences have been demonstrated to enhance students' conceptual understanding, scientific reasoning, and problem-solving skills. Nevertheless, the efficacy of laboratory instruction can be influenced by diverse factors, such as teaching methodologies, curriculum design, and students' prior knowledge and experiences. One of the crucial competencies assessed in physics laboratory work is the ability to properly and accurately utilize measurement instruments. As Riskawati and Andriani Andi Arie (2018) emphasize, "Proficiency in the use of measuring devices is an indispensable skill for students to master in physics laboratory work, as it directly impacts the quality and reliability of the data collected." Developing this skill is imperative, as it forms the foundation for conducting experiments, collecting data, and ultimately, drawing valid conclusions from empirical observations.

Furthermore, the accurate use of measurement instruments is closely tied to the development of scientific reasoning and problem-solving abilities, which are widely recognized as essential outcomes of practical laboratory experiences (Singer et al., 2018). As Linn et al. (2015) assert, "The ability to select and utilize appropriate measurement tools, while considering factors such as precision and uncertainty, is a fundamental aspect of scientific inquiry and a key indicator of students' readiness for advanced laboratory work" (p. 628). Consequently, assessing students' proficiency in this domain is critical for identifying areas of strength and areas for improvement, informing targeted instructional strategies, and fostering a deeper understanding of scientific practices.

In the context of physics education, several studies have highlighted the significance of hands-on laboratory activities in promoting conceptual understanding and developing practical skills (Sharma et al., 2015; Wieman & Holmes, 2015). Similarly, in chemistry education, laboratory work has been recognized as a crucial component for fostering skills such as data analysis, interpretation, and experimental design (Hofstein & Mamlok-Naaman, 2007). In the field of biology education, laboratory experiences have been shown to enhance students' understanding of complex biological processes and encourage the development of scientific inquiry skills (Brownell et al., 2014; Gormally et al., 2016). However, there is limited research comparing the acquisition of practical laboratory skills across different science disciplines, particularly in the early stages of undergraduate education.

Practical laboratory skills are integral to science education, providing students with hands-on experience and fostering a deeper understanding of theoretical concepts (Hofstein & Lunetta, 2004). In the context of first-semester students enrolled in Physics, Chemistry, and Biology Education programs, the acquisition of these skills lays the foundation for their future scientific endeavors. However, while the importance of practical laboratory work is widely acknowledged, there is limited research comparing the proficiency levels of students across different science disciplines, particularly in the early stages of their academic journey. Brownell et al. (2014) highlighted the importance of hands-on laboratory experiences in fostering the development of scientific reasoning and problem-solving skills. Exploring the relative effectiveness of laboratory instruction across Physics, Chemistry, and Biology Education programs may provide significant contributions to the enhancement of teaching methodologies and curriculum design. These contributions have the potential to guide educators in identifying areas for enhancement and refinement in practical training strategies, thereby enriching students' educational experiences and academic accomplishments.

Thus, this study seeks to fill this gap by investigating and comparing the practical laboratory skills of first-semester students enrolled in Physics, Chemistry, and Biology Education programs at [University Name]. By identifying any variations in skill acquisition among these disciplines, this research aims to provide evidence-based recommendations for enhancing laboratory instruction and curriculum development in science education. By conducting a comparative analysis of laboratory skill development among first-semester students in Physics, Chemistry, and Biology Education programs, this study aims to contribute to the existing body of knowledge and provide insights into tailoring laboratory instruction to meet the specific needs of students across different science disciplines.

METHODS

The study will involve first-semester students enrolled in Physics, Chemistry, and Biology Education programs at PMIPA FKIP Universitas Mataram. A stratified random sampling method will be employed to select participants from each program, ensuring representativeness and minimizing potential biases. The target sample size will be determined based on statistical power analysis and effect size estimations from prior related studies.

Practical laboratory skills will be assessed using a standardized rubric developed in accordance with established educational guidelines and best practices in science education (Hofstein & Lunetta, 2004; Brownell et al., 2014). The rubric will cover essential competencies such as experimental design, data collection, analysis, interpretation, communication, and laboratory safety.

Each participant will perform a series of laboratory experiments relevant to their respective disciplines under the supervision of experienced instructors. The experiments will be carefully chosen to assess a wide range of skills and concepts taught in the first semester of each program, ensuring alignment with the respective curricula. Students' performance during the experiments will be observed and recorded by trained evaluators using the standardized rubric. Evaluators will undergo comprehensive training on rubric application and standardization procedures to ensure consistent and reliable scoring.

Quantitative data on participants' performance will be collected based on the rubric scores assigned by evaluators. The collection of data through structured rubrics is a widely accepted practice in assessing practical laboratory skills. As noted by Brownell et al. (2014), "Rubrics provide a consistent and objective framework for evaluating students' proficiency in various aspects of laboratory work, such as experimental design, data analysis, and scientific communication" (p. 40). The utilization of rubrics not only ensures standardization in the assessment process but also facilitates the identification of specific areas where students may require additional support or targeted instruction.

The statistical analysis of the collected data will be executed using the Minitab software, a powerful tool widely used in educational research and data analysis. As

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highlighted by Minitab Inc., "Minitab offers a comprehensive set of statistical tools for both parametric and non-parametric tests, enabling researchers to conduct various analyses tailored to their specific research objectives" (2021). The software's capabilities will facilitate tests for normality on the three distinct data sets corresponding to each education program, ensuring the appropriate use of statistical tests based on the distribution of the data.

Furthermore, the use of non-parametric tests, such as the Mann-Whitney U test, will be employed for comparative analyses between the education programs. As stated by Nachar (2008), "The Mann-Whitney U test is a robust non-parametric alternative to the independent-samples t-test, particularly useful when the assumptions of normality or homogeneity of variance are violated" (p. 13). By utilizing this non-parametric approach, the study will ensure the appropriate comparison of practical laboratory skill acquisition levels across the Physics, Chemistry, and Biology Education programs, regardless of the underlying distribution of the data.

By employing this rigorous methodology, the study aims to provide valuable insights into the comparative effectiveness of laboratory instruction in Physics, Chemistry, and Biology Education programs, contributing to evidence-based improvements in science education and fostering proficient skill development across diverse disciplines.

FINDINGS AND DISCUSSION

The data related to the practical skills of biology, chemistry, and physics education students will be presented in figures and tables in the findings section, and extensively discussed in the discussion section,

Findings

The normality data of students majoring in biology education is depicted in Figure 1, chemistry education in Figure 2, and physics education in Figure 3. Descriptive statistical data is displayed in Table 1. The comparison between the two groups is conducted using the non-parametric Mann-Whitney test and illustrated in Figure 4. The comparison between biology education and physics education students is presented in Figure 5, chemistry education and physics education in Figure 6, and chemistry education and biology education in Figure 7.

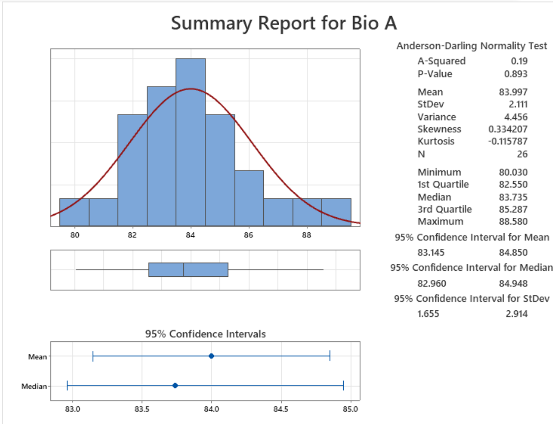

Figure 1. Summary Report for Bio A

The analysis results for group Bio A (Bio A represents students majoring in biology education) displayed a distribution that appears to follow a normal pattern, as indicated by the Anderson-Darling Normality Test with an A-Squared value of 0.19 and a P-value of 0.893. Descriptive statistics show a mean of 83.997 and a standard deviation of 2.111, with the median at 83.735 and quartiles ranging from 82.550 to 88.580. Skewness is measured at 0.334207, while kurtosis is at -0.115787. The 95% confidence intervals for the mean (83.145 - 84.850), median (82.960 - 84.948), and standard deviation (1.655 - 2.914) provide reliable estimates of the population parameters, offering valuable insights into the characteristics of the dataset for group Bio A.

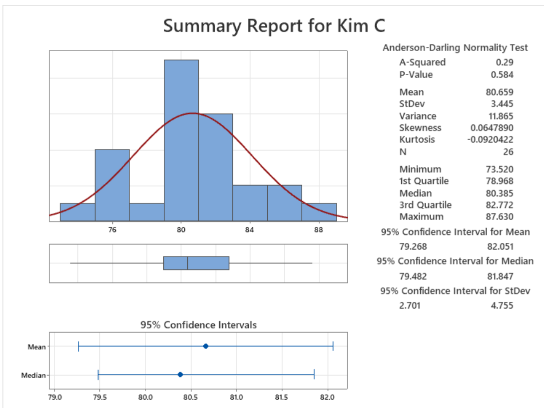

Figure 2. Summary Report for Kim C

The analysis outcomes for Kim C(Kim C represents students majoring in chemistry education) reveal a distribution that demonstrates characteristics of a normal distribution, as illustrated by the Anderson-Darling Normality Test results with an A-Squared value of 0.29 and a P-value of

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0.584. The descriptive statistics showcase a mean of 80.659 and a standard deviation of 3.445, with the median at 80.385 and quartiles spanning from 73.520 to 87.630. Skewness is calculated at 0.0647890, while kurtosis is -0.0920422. The 95% confidence intervals for the mean (79.268 - 82.051), median (79.482 - 81.847), and standard deviation (2.701 - 4.755) provide robust estimations of the population parameters, delivering valuable insights into the dataset's characteristics for Kim C.

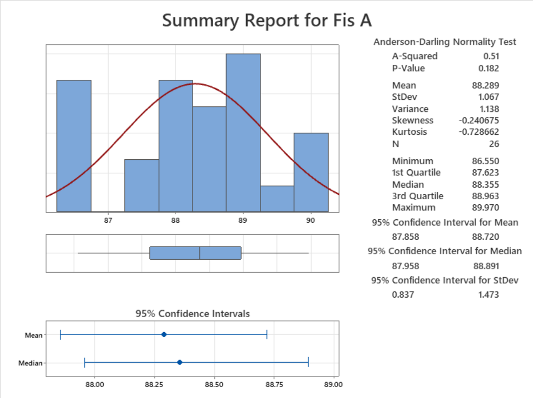

Figure 3. Summary Report for FIS A

The analysis conducted on group Fis A (Fis A represents students majoring in physics education) illustrates a distribution that appears to be relatively normal, as evidenced by the Anderson-Darling Normality Test results showing an A-Squared value of 0.51 and a P-value of 0.182. The descriptive statistics reveal a mean of 88.289 and a standard deviation of 1.067, with the median at 88.355 and quartiles ranging from 86.550 to 89.970. Skewness is observed at -0.240675, while kurtosis stands at -0.728662. The calculated 95% confidence intervals for the mean (87.858 - 88.720), median (87.958 - 88.891), and standard deviation (0.837 - 1.473) offer robust estimates of the population parameters, providing valuable insights into the characteristics of the dataset for group Fis A.

Table 1. Descriptive Statistics: Bio A, Kim C, Fis A

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Bio A	26	0	83.997	0.414	2.111	80.030	82.550	83.735	85.287	88.580
Kim C	26	0	80.659	0.676	3.445	73.520	78.968	80.385	82.772	87.630
Fis A	26	0	88.289	0.209	1.067	86.550	87.623	88.355	88.963	89.970

In Table 1, it is observed that the Fis A variable exhibits the highest mean value of 88.289 among the three variables, indicating superior performance compared to Bio A (mean = 83.997) and Kim C (mean = 80.659). This finding suggests that students in the Physics Education program (Fis A) tend to achieve higher scores or demonstrate better proficiency in the assessed laboratory skills compared to their counterparts in the Biology Education (Bio A) and Chemistry Education (Kim C) programs. Moreover, the Fis A variable demonstrates the smallest standard deviation of 1.067, implying a more concentrated distribution of data points around the mean. This lower variability in scores showcases a remarkable level of consistency in the performance of students within the Physics Education program. A smaller standard deviation indicates a more homogeneous distribution of data, suggesting a higher degree of uniformity in the observed phenomenon. Conversely, the larger standard deviations observed for Bio A (2.111) and Kim C (3.445) suggest greater variability in the performance of students within these programs.

It is noteworthy that the Fis A variable also exhibits the highest median (88.355) and third quartile (Q3 = 88.963) values compared to the other variables, further reinforcing the notion of superior performance in this group. As highlighted by Yin and Shavelson (2008), "Examining quartile values provides valuable insights into the distribution of data, particularly in identifying potential outliers or skewness" (p. 38). The consistency in higher values across various measures of central tendency for Fis A underscores the robustness of the observed trend.

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Mann-Whitney: Bio A, Fis A

Method

η_1: median of Bio A
η_2: median of Fis A
Difference: $\eta_1 - \eta_2$

Descriptive Statistics

Sample	N	Median
Bio A	26	83.735
Fis A	26	88.355

Estimation for Difference

Difference	CI for Difference	Achieved Confidence
-4.52	(-5.29, -3.48)	95.09%

Test

Null hypothesis $H_0: \eta_1 - \eta_2 = 0$
Alternative hypothesis $H_1: \eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	378.00	0.000
Adjusted for ties	378.00	0.000

Figure 4. Mann-Whitney: Bio A, Fis A

The Minitab analysis, utilizing the Mann-Whitney test to compare groups Bio A and Fis A, revealed notable findings. Descriptive statistics show that Bio A with N = 26 had a median of 83.735, while Fis A also with N = 26 displayed a higher median of 88.355. The calculated difference in medians was -4.52, with a 95.09% Confidence Interval of (-5.29, -3.48). The test results rejected the Null Hypothesis (H_0) of no difference in medians for the Alternative Hypothesis (H_1) indicating a significant disparity. A P-Value of 0.000 (below 0.05) further supported the statistical significance of this difference. The W-Value of 378.00 and an adjusted P-Value of 0.000 emphasized the robustness of these results. In conclusion, the Mann-Whitney test highlights a substantial discrepancy in median scores between Bio A and Fis A, favoring Fis A with significantly higher median performance over Bio A.

Mann-Whitney: Kim C, Fis A

Method

η_1: median of Kim C
η_2: median of Fis A
Difference: $\eta_1 - \eta_2$

Descriptive Statistics

Sample	N	Median
Kim C	26	80.385
Fis A	26	88.355

Estimation for Difference

Difference	CI for Difference	Achieved Confidence
-7.73	(-8.92, -6.49)	95.09%

Test

Null hypothesis $H_0: \eta_1 - \eta_2 = 0$
Alternative hypothesis $H_1: \eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	358.00	0.000
Adjusted for ties	358.00	0.000

Figure 5. Mann-Whitney: Kim C, Fis A

The analysis conducted in Minitab using the Mann-Whitney test to compare the groups Kim C and Fis A provided insightful outcomes. Descriptively, Kim C with N = 26 exhibited a median of 80.385, while Fis A also with N = 26 displayed a higher median of 88.355. The difference in medians was calculated to be -7.73 with a 95.09% Confidence Interval of (-8.92, -6.49). The test results rejected the Null Hypothesis (H_0) of no difference in medians between the groups in favor of the Alternative Hypothesis (H_1) indicating a significant disparity. The low P-Value of 0.000 (below 0.05) confirmed the statistical significance of this difference. The W-Value of 358.00 and the adjusted P-Value of 0.000 further supported the validity of the observed distinctions. In summary, the Mann-Whitney test highlighted a substantial divergence in median scores between Kim C and Fis A, with Fis A demonstrating markedly superior performance compared to Kim C.

Mann-Whitney: Kim C, Bio A

Method

η_1: median of Kim C
η_2: median of Bio A
Difference: $\eta_1 - \eta_2$

Descriptive Statistics

Sample	N	Median
Kim C	26	80.385
Bio A	26	83.735

Estimation for Difference

Difference	CI for Difference	Achieved Confidence
-3.305	(-4.86, -1.8)	95.09%

Test

Null hypothesis	$H_0: \eta_1 - \eta_2 = 0$
Alternative hypothesis	$H_1: \eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	486.00	0.000
Adjusted for ties	486.00	0.000

Figure 6. Mann-Whitney: Kim C, Bio A

The Minitab analysis conducted on the dataset from figure 6 using the Mann-Whitney test to compare the groups Kim C and Bio A revealed insightful findings. The descriptive statistics indicate that Kim C with N = 26 has a median of 80.385, while Bio A also with N = 26 has a higher median of 83.735. The estimation for the difference in medians shows a value of -3.305 with a 95.09% Confidence Interval of (-4.86, -1.8). The test results reject the Null Hypothesis (H_0) of a zero difference in medians between the two groups in favor of the Alternative Hypothesis (H_1) that the medians differ significantly. The obtained P-Value of 0.000 (less than 0.05) further supports this conclusion. The W-Value of 486.00 and the adjusted P-Value of 0.000 emphasize the statistical significance of the differences observed. In summary, the Mann-Whitney test highlights a substantial disparity in median scores between Kim C and Bio A, indicating that Bio A outperforms Kim C significantly.

Discussion

The study investigates the proficiency levels of first-semester students in Physics, Chemistry, and Biology education programs through an in-depth analysis of their fundamental laboratory skills. The findings indicate that students in the Physics group (Fis A) exhibit exceptional performance, characterized by a mean value of 88.289 and a minimal standard deviation of 1.067, showcasing a more uniform skill set compared to their peers in the Biology (Bio A) and Chemistry (Kim C) groups. These results offer valuable insights for educators to personalize teaching methodologies and enhance curricula across these disciplines, thereby contributing to the advancement of science education programs and fostering enhanced student learning outcomes across various scientific domains.

The application of the Mann-Whitney test in the Minitab analysis to assess the fundamental physics laboratory skills of first-semester Physics students has unveiled significant disparities. A comparison between groups Bio A and Fis A reveals a notable difference in median scores, with Fis A demonstrating a significantly higher median of 88.355 in contrast to Bio A's 83.735. The calculated median difference of -4.52, supported by a 95.09% Confidence Interval of (-5.29, -3.48), underscores the statistically substantial performance gap favoring Fis A. The rejection of the Null Hypothesis (H_0) in favor of the Alternative Hypothesis (H_1), reinforced by a P-Value of 0.000, emphasizes the robustness of these findings. Similarly, the comparison between groups Kim C and Fis A highlights a marked difference in median scores, with Fis A displaying superior performance, evidenced by a higher median of 88.355 compared to Kim C's 80.385. The outcomes emphasize a significant disparity in laboratory skills proficiency between these student groups, underscoring the superior performance of Physics program students over their counterparts in the Biology and Chemistry programs.

CONCLUSION

The research on the proficiency levels of first-semester students in Physics, Chemistry, and Biology education programs reveals significant disparities in laboratory skills. Students in the Physics group (Fis A) demonstrated superior performance with a mean of 88.289 and low standard deviation, highlighting consistent skills compared to peers in Biology (Bio A) and Chemistry (Kim C) groups. These findings offer valuable insights for educators to enhance teaching strategies and curricula, improving science education programs and student outcomes across scientific fields. The Mann-Whitney test results emphasized substantial differences in laboratory skills proficiency among student groups. In comparisons between Bio A and Fis A, Fis A displayed a significantly higher median, supported by a confidence interval and a P-Value underlining the statistical significance. Similarly, Fis A outperformed Kim C, indicating notable distinctions in performance across programs. These results underscore the superior performance of Physics students and provide implications for educational enhancements in diverse scientific disciplines.

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