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Gender-Neutral Outcomes in IoT-Based Physics Education: A Non-Parametric Analysis of Hands-On IoT Tasks and Cognitive Achievement

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ABSTRACT

This study aims to test the difference in practicum performance and cognitive ability between male and female students in making an IoT-based physics learning media project in the Physics Learning Media course. The research method used was descriptive-quantitative with a sample of 43 students (37 females, 6 males) of the class of 2022 at the Department of Physics Education, Sultan Ageng Tirtayasa University. The data collection instrument used a Hands-on Task (4 IoT practicum tasks) and a cognitive test in the form of an essay. Then the data were analyzed descriptively and inferentially (Mann-Whitney U Test). The results showed that there was no significant difference between genders in all practicum assignments ($p = 0.320–0.981$) or cognitive tests ($p = 0.724$). The average male scores were slightly higher on tasks 3–4 (83.33–89.17) and cognitive tests (3.68), but not statistically significant. These findings prove that IoT-based learning has the potential to create equality of technical and conceptual competencies, regardless of gender. Implicitly, the *experiential learning approach* with IoT projects needs to be optimized to encourage the active participation of all genders in STEM.

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INTRODUCTION

Gender differences in academic achievement, particularly in STEM (Science, Technology, Engineering, and Mathematics) fields, are still a controversial issue, with several studies showing disparities in intergender performance in learning using technology (García-Holgado & García-Peñalvo, 2022; Hasruddin & Evi, 2020; Thomas, 2022), while other studies stated that there was no significant difference (Fitri & Chairoel, 2019; Zamista & Charona, 2023). In the context of IoT-based physics learning (Internet of Things), technical skills such as programming and systems design are often associated with male dominance, although there is no strong empirical evidence in the higher education environment in Indonesia. Previous studies have focused more on gender differences in mathematical or general science abilities (Afriana et al., 2016; Cahyono, 2017; Hasruddin & Evi, 2020), but have not touched on specific aspects such as the development of IoT-based physics learning media, as well as the limited research that integrates practicum performance assessment and cognitive tests in a single design to describe the holistic impact of *experiential learning methods*.

Mastery of the skills of making physics learning media, especially IoT-based, is a crucial competency for students majoring in physics education as prospective teachers (Hermansyah et al., 2015). This ability not only supports the achievement of teachers' professional competency standards, such as mastery of materials, development of innovative teaching materials, and the application of educational technology (Erfan et al., 2020). But it also equips them to design learning media that is inclusive, gender-responsive, and based on student needs (Lia, 2018). Professional teachers are required not only to master scientific content, but also to be able to utilize technology to create an immersive and equal learning experience for all students, including in reducing gender bias that may arise from media design or teaching methods (Husamah, 2024).

This research provides several important benefits, both theoretically and practically. Theoretically, this research enriches the literature review on the relationship between gender and project-based learning, especially in the context of developing Internet of Things (IoT)-based physics learning media. Research by (Wang & Degol, 2017), found that technology projects emphasize technical skills more than gender backgrounds, while (Lai, 2024), highlights the effectiveness of IoT integration with critical reflection for conceptual understanding, but both studies have not addressed the context of gender equality in Physics Learning Media courses. In practice, this study provides empirical insights for educators in designing inclusive and responsive learning for gender diversity. Students, both male and female, are expected to be encouraged to participate equally in educational technology development projects, while building critical awareness of gender bias and stereotypes that may arise in the learning process. For educational institutions, the results of this study can be the basis for formulating policies or curriculum designs that encourage gender equality, especially in the fields of science and technology. In addition, this study contributes to the development of a project-based learning approach that is empirically tested and can be replicated in similar contexts. By integrating IoT and critical reflection in learning, this study also supports the strengthening of 21st-century skills, such as problem solving, cross-gender collaboration, technological literacy, and critical thinking among student educators. Therefore, this study aims to directly test gender assumptions in a project-based inclusive learning environment, with the formulation of the problem: *Is there a significant difference between practicum performance and cognitive ability of male and female students in the development of IoT-based physics learning media?*

METHODS

This study uses a descriptive-comparative quantitative design to analyze the difference in practicum performance and cognitive ability between male and female students in the Physics Learning Media course. The research population consists of one class with 53 students in the Department of Physics Education, Sultan Ageng Tirtayasa University, class of 2022. However, after data cleaning (some students participated in the independent campus program), the valid sample amounted to 43 students (37 women, 6 men). Data was collected through two main instruments: practicum scores from four IoT project assignments assessed using structured student worksheets, and cognitive learning outcomes tests in the form of essays.

Worksheets and learning outcome tests have gone through a validation process in previous research (Nurlia et al., 2024). Student worksheet validation includes expert assessment of material suitability, clarity of instruction, and suitability with Course Learning Outcomes (CLO). Meanwhile, the validation of the learning outcome test is carried out through a content validity test. In this study, student worksheets were used to guide students in designing, programming, and testing IoT systems, while learning outcome tests measured conceptual understanding through essay and multiple-choice questions that had been adjusted to CLO indicators.

Statistical analysis was carried out in two stages. First, descriptive analysis calculated the mean and Standard Deviation (SD) of task scores 1–4 and cognitive tests for each gender. Second, an inferential analysis using the Mann-Whitney U Test (*α=0.05) to compare differences between genders was chosen because the sample size of the male sample was small (n=6) and the assumption of data normality was not met. The analysis process was carried out with the help of SPSS software version 26*. The main limitations of this study include the imbalance of the gender sample (the number of men is much smaller) and the scope of assessment that is limited to technical and cognitive aspects, without covering creativity or collaboration skills. Nonetheless, the use of validated instruments (student worksheets and learning outcome tests) and transparent data cleansing procedures increases the internal validity of the research. The results of this study can be the basis for further studies with longitudinal designs or more balanced samples, especially in the context of experiential learning based on learning and gender equality in STEM.

RESULTS AND DISCUSSION

This study is to test gender assumptions in an inclusive project-based learning environment, focused on analyzing differences in practicum performance and cognitive abilities between male and female students in the development of Internet of Things (IoT)-based physics learning media. The formulation of the problem raised, namely whether there is a significant difference between the two groups of students, is the basis for designing the research approach and method. Therefore, the following presentation of the results will outline the main findings obtained from the data analysis, in order to answer the formulation of the problem and assess the extent to which the objectives of this study have been achieved.

Practicum Performance Results (Portfolios 1-4)

Table 1 shows the results of the comparative analysis of practicum scores between male (M) and female (F) students using the Mann-Whitney U Test (α = 0.05):

Table 1. Mann-Whitney U analysis on practicum performance by gender

Task	Gender	N	Mean ± SD	U Statistics	P-value	Interpretation
1	M	6	85.83 ± 9.83	111.5	0.981	There is no significant difference
	F	37	86.70 ± 7.45			
2	M	6	84.17 ± 10.03	107.0	0.873	There is no significant difference
	F	37	86.30 ± 10.52			
3	M	6	83.33 ± 6.83	103.5	0.787	There is no significant difference
	F	37	83.89 ± 16.33			
4	M	6	89.17 ± 3.76	88.0	0.320	There is no significant difference.
	F	37	87.65 ± 7.72			

The four practicum assignments in this study are designed in stages to measure students' technical competence according to CLO 4, starting from basic mastery of *microcontrollers* to complex IoT applications. In Assignment-1, students implemented simple controls using the Arduino IDE and Wemos D1 R1, such as programming a DHT11 sensor to measure room temperature, which tested the ability to integrate hardware-software. The use of microcontrollers such as in project-based learning can improve students' understanding of the concept of the Internet of Things (IoT) and embedded system programming (Prihatmoko, 2016). Task-2 focuses on automated control through the Blynk IoT platform, for example, designing an automated irrigation system based on soil moisture conditions, to evaluate the understanding of algorithms and cloud computing. Task-3 involved developing Blynk's *web dashboard* to visualize *real-time* IoT data, while Task-4 challenged students to optimize IoT systems through mobile applications, testing technology adaptations in real-life contexts. The results of statistical analysis in Table 1 showed no significant difference ($p > 0.05$) between the scores of male and female students in the four tasks, although the average scores of men were slightly higher in Task-3 (83.33 vs. 83.89) and Task-4 (89.17 vs. 87.65). These findings are in line with Bandura's (Calicchio, 2023) theory of *self-efficacy*, which emphasizes that success in performance-based tasks is determined by skill mastery, not gender identity. reinforce this argument by showing that objectively structured technology projects, such as assessments based on code accuracy and system function, tend to result in equality of outcomes between genders.

This competency equivalence is driven by a combination of collaborative learning methods and performance-based assessment. Vygotsky's social-constructivist principles are implemented through group work, in which students play the role of more *knowledgeable others* (MKOs), facilitating the transfer of technical knowledge without gender bias. This collaboration is strengthened by the findings of (Moyano et al., 2023), who stated that an inclusive group environment reduces stereotype *threats* in STEM. On the other hand, the use of objective assessment rubrics, such as evaluation of sensor function and system reliability, eliminates room for subjective bias, as recommended by UNESCO in its gender-responsive STEM education guidelines. The connection with CLO-4 can be seen from the ability of students to produce functional IoT prototypes, such as MPU6050 sensor-based acceleration measuring devices, that meet the standards for the development of physics learning media. These results are also in line with Edgar Dale's Experience Cone theory, where hands-on learning through practicum (the second level of the cone) increases knowledge retention by up to 70%, while confirming the findings of (Stupuriene et al., 2022), that IoT practicum improves *problem-solving skills* and *technical confidence* without gender disparity. Thus, this study not only proves the effectiveness of the IoT approach in creating competency equity but also highlights the importance of learning designs that integrate hands-on experience, objective assessment, and inclusive collaboration to achieve equitable STEM education goals.

Cognitive Learning Outcomes Test

The results of the cognitive learning test are shown in Table 2.

Table 2. Mann-Whitney U analysis on gender-specific cognitive learning outcome tests

Gender	N	Mean ± SD	U Statistics	P-value	Interpretation
M	6	3.68 ± 0.25	85.5	0.724	There is no significant difference.
F	37	3.63 ± 0.30			

The results of statistical analysis in Table 2 confirm that there is no significant difference between the cognitive test scores of male and female students (p = 0.724), although there is a minimal average difference (3.68 vs. 3.63). The distribution of the scores of the two groups showed similarity in pattern, with identical median (3.7) and overlapping range of scores (3.3–4.0 for males vs. 3.0–4.0 for females). These findings are in line with Kurni & KG (2024), who assert that an IoT-based learning approach that combines *hands-on experience* (such as sensor programming) with *critical reflection* (through cognitive tests) can neutralize gender bias by focusing on competency mastery. The cognitive tests in this study not only measure the theoretical understanding of IoT (e.g., the working principle of the DHT11 sensor in physics), but also the ability of students to evaluate its pedagogical implications, such as increased *student engagement* and the integration of IoT into the science education curriculum (CLO 5). A concrete example can be seen in the students' analysis of IoT-based environmental monitoring system projects, where they can criticize the impact of the technology on learning efficiency and its relevance to industry needs.

The consistency of intergender outcomes was also reflected in the practicum assessment (CLO 4), in both groups demonstrating equal ability to design IoT prototypes using the Wemos D1 R1 and the Blynk platform. This reinforces (Moritz's, 2018) finding that structured project-based learning *environments*, such as the use of *objective assessment rubrics* and *instructional scaffolding*, can minimize gender disparities in STEM. However, (UNESCO, 2017), in its report *"Cracking the code: girls' and women's education in science, technology, engineering and mathematics (STEM)"* reminds that equality of outcomes does not always guarantee equal access, especially in terms of gender representation at the level of project leadership or mentoring opportunities. Nonetheless, the active participation of female students in this study shows that an inclusive academic environment, supported by campus policies that facilitate access to IoT tools and technical training, has succeeded in creating an equitable learning ecosystem (Lestari et al., 2023).

Behind these positive findings, the study has some critical limitations. First, gender imbalances (6 males vs. 37 females) have the potential to affect external validity, particularly in generalizations to populations with more balanced gender distributions (Sarie et al., 2023). Second, the scope of assessment that is limited to technical *skills* and cognitive aspects (*conceptual understanding*) has not touched other dimensions such as design creativity, collaboration skills, or *problem-solving* in real scenarios—aspects that are key indicators of the readiness of STEM graduates in the era of the Industrial Revolution 4.0. For this reason, the recommendations of this study include: 1) Development of cross-gender collaborative IoT projects, such as thematic *hackathons* with an emphasis on *interdisciplinary teamwork* (e.g., integration of IoT with environmental or health sciences), to strengthen the achievement of CLO 4 while testing the dynamics of collaboration between genders. 2) Integration of holistic assessment instruments such as *creative thinking rubrics* (referring to the Torrance Tests of Creative Thinking) and *peer-assessment* to evaluate innovation and social skills, thus supporting CLO 5 comprehensively, and 3) Expansion of the research context to multidisciplinary fields (e.g. IoT in biotechnology or *smart agriculture*) with a larger and balanced sample, to test the consistency of findings in a variety of disciplines.

CONCLUSION

This study revealed that there was no significant difference between practicum performance and cognitive ability of male and female students in the IoT-based Physics Learning Media course. The results of statistical analysis using the Mann-Whitney U Test ($p > 0.05$) on the four practicum tasks (Arduino IDE, Blynk IoT platform, web dashboard, and mobile apps) as well as cognitive tests showed equality in achievement between genders. These results support the importance of inclusive IoT-based learning to achieve competency equity in STEM education. The findings also suggest that technology-based learning approaches can reduce gender bias in the acquisition of digital and technical skills. Thus, the integration of IoT into the science curriculum not only improves students' general competence but also encourages the creation of an equal and fair learning environment for all.

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