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Evaluating the Impact of Professional Development on STEAM Education Competency in the Industrial Revolution 5.0 Era

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Abstract
This research evaluates the impact of the Teacher Professional Education (PPG) program for Kindergarten educators on their understanding of Science, Technology, Engineering, Arts, and Mathematics (STEAM) education in the context of the Industrial Revolution 5.0 and Society 5.0. Utilizing a quantitative approach with a pretest-posttest design, the study involved fifty kindergarten teachers from the PPG Daljab (In-Service Teacher Professional Education) at FITK, UIN Sunan Kalijaga. The assessment of participants, conducted through validated instruments, focused on measuring the enhancement of pedagogical competencies in STEAM before and after the program. Results indicated a notable improvement in the teachers' competencies post-intervention. The statistical analysis, including a paired t-test, showed a significant increase in test scores from the pretest to the post-test with a t-statistic of -53.58 and a p-value of 8.54 x 10^-44, highlighting a highly significant difference and validating the effectiveness of the PPG program in bolstering STEAM educational skills. Further tests for normality and homoscedasticity confirmed the reliability and validity of the data. Despite these positive outcomes, variations in test item reliability suggest the need for ongoing evaluation and refinement of assessment tools. The study underscores the potential of structured professional development programs in enhancing teacher capabilities, particularly in adapting to the demands of modern technological and interdisciplinary educational environments. It recommends further research to explore the long-term effects of such interventions on teacher competencies and to fine-tune the assessment methodologies used. This study contributes to the understanding of effective professional development in preparing educators to integrate and excel in STEAM disciplines, aligning with the educational imperatives of contemporary technological revolutions.

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Introduction

The Industrial Revolution 5.0 has catalyzed a paradigm shift in numerous sectors, including education, necessitating an adaptive and forward-thinking approach to teaching and learning (Sari et al., 2019). This era emphasizes the integration of advanced digital technologies into everyday life, presenting opportunities and challenges for educators worldwide. As such, STEAM (Science, Technology, Engineering, Arts, Mathematics) education has become crucial in preparing students to thrive in a technologically integrated society (Roche et al., 2021). The focus on STEAM supports a balanced understanding of interdisciplinary connections and fosters the critical thinking and creative problem-solving skills essential for the 21st century (Sabarudin et al., 2022). Therefore, the effective implementation of STEAM methodologies in teacher professional development programs is pivotal for educational excellence and societal advancement (Izzati et al., 2019; Jorg et al., 2007; Yakman & Lee, 2012).

Historically, the push for STEAM education has been driven by the need to bridge the gap between scientific, artistic, and mathematical disciplines, promoting a holistic approach to solving complex problems (Bagiati et al., 2018; Culén & Gasparini, 2019; Katz-Buonincontro, 2023; Wu, 2022). Reforms such as the National Movement for Mental Revolution have been initiated to embed these interdisciplinary approaches within curricula to enhance higher-order

thinking skills (Kemendikbud, 2018). Despite these efforts, the practical application of STEAM in educational settings remains a challenge, as many educators still grapple with integrating these concepts into their teaching practices (Gunawan et al., 2020; Jorg et al., 2007; Moore, 2002; Zulfitri et al., 2019). Theoretical acceptance of STEAM's value contrasts sharply with its practical implementation, highlighting a gap in teacher preparedness and confidence (Rahmawati, 2020). Addressing this gap requires comprehensive professional development programs introducing STEAM concepts and ensuring their effective integration into daily teaching activities.

The effectiveness of professional development in STEAM education has been evidenced by various programs that have successfully enhanced teacher competencies and confidence. Programs that blend theoretical knowledge with practical application, like workshops and hands-on projects, have shown promising results in improving educators' ability to implement STEAM methodologies (Chuong et al., 2023; Lu et al., 2022). For instance, initiatives such as the CanSat projects involve teachers designing and implementing mini satellite projects, providing them with experiential learning that directly translates into classroom teaching (Coronel et al., 2020). Such practical experiences are crucial in helping teachers overcome the initial hesitation and unfamiliarity with STEAM, paving the way for more innovative and integrated teaching practices.

Continued support and ongoing professional development are essential for the sustained implementation of STEAM education. Research shows that support mechanisms like peer coaching and collaborative teaching frameworks significantly contribute to the long-term success of STEAM integration in schools (Fenwick & Kelly, 2023; Shyshenko et al., 2022). These approaches encourage a culture of continuous learning and adaptation among teachers, vital in keeping pace with the rapid technological advancements that characterize the Industrial Revolution 5.0. Furthermore, using digital platforms and online teaching tools has been identified as beneficial in enhancing students' engagement and learning outcomes in STEAM subjects (Guo et al., 2024; Zhang, 2023).

Despite progress, significant gaps and controversies remain regarding the best practices for implementing STEAM education effectively across different educational settings. Questions persist about these programs' scalability and adaptability to diverse educational and cultural contexts (Boice et al., 2021; Yopi, 2021). Additionally, there is a notable lack of comprehensive studies examining these professional development interventions' long-term impacts on teacher practices and student outcomes. Addressing these gaps is crucial for developing effective strategies that can be applied globally, ensuring all students benefit from a high-quality STEAM education.

This study aims to contribute to the field by evaluating the impact of the Teacher Professional Education Program (PPG) Kindergarten education Teacher In-Service Teacher Professional Education on enhancing teachers' understanding and implementation of STEAM methodologies. Focusing on the qualitative and quantitative changes in teaching practices before and after participation in the PPG, the research seeks to provide a detailed analysis of the program's effectiveness. The findings are expected to offer valuable insights into optimizing professional development programs and influencing future educational policies and strategies. Additionally, this study will explore the contextual factors that influence the success of STEAM education, providing a comprehensive understanding of the variables at play.

Ultimately, the research aims to delineate effective strategies for integrating STEAM education within the professional development framework for educators. The study will inform policy decisions and educational practices globally by identifying the elements contributing to the successful implementation and sustained use of STEAM methodologies. The anticipated contributions of this research include enhanced teacher competencies, improved student outcomes, and a robust framework for the continuous development of STEAM education. This study not only addresses the existing gaps in the literature but also serves as a practical guide for educators and policymakers aiming to equip future generations with the skills necessary to navigate and excel in the Industrial Revolution 5.0 and Society 5.0.

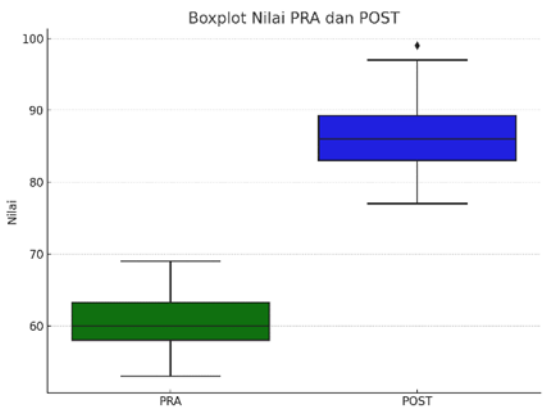
Methods

This study employed a quantitative research design to explore the advancements in STEAM education following teacher participation in post-professional development during the Industrial Revolution 5.0 era. The research used a descriptive approach to quantitatively depict the current phenomena related to individual and group characteristics within the educational context (Sugiyono, 2015; Sukmadinata, 2016). The population consisted of students from PPG Daljab (In-Service Teacher Professional Education) FITK at UIN Sunan Kalijaga, with a sample of 50 participants selected through random sampling. The core methodology incorporated a pretest-posttest design to evaluate variable changes before and after the educational intervention. The research procedure began with a baseline measurement (pretest) before the intervention, followed by a subsequent measurement (posttest) to assess the effects of the educational strategies.

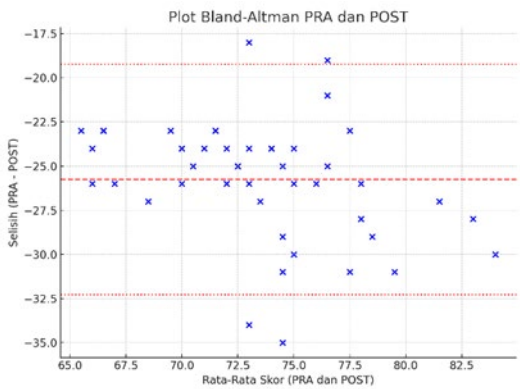
Tools and technologies utilized in the study included validated measurement instruments for both pretest and posttest phases. Reliability was assessed using Cronbach's Alpha, whereas the normality and homogeneity of the data were examined using the Shapiro-Wilk and Levene's tests, respectively. Data collection was meticulously carried out using these standardized instruments. The subsequent analysis employed statistical methods such as tests for normality, homoscedasticity, reliability, and paired t-tests to ascertain significant differences between pretest and posttest scores. To ensure robustness and accuracy, validity tests were conducted to verify that each measurement item accurately measured the intended constructs, with additional evaluations for items that exhibited low or non-significant correlations. The comprehensive design and rigorous implementation of these methodologies were aimed at providing reliable and valid results, enabling precise interpretations regarding the effectiveness of the intervention in enhancing teachers' comprehension of STEAM education in the era of the Industrial Revolution 5.0. Data analysis was performed using the statistical software R, adhering to a structured research plan depicted in the study's implementation diagrams (Creswell & Guetterman, 2019).

Result

3.1. Validity Test Explained



(1)



(2)

Figure 1. Boxplot of Pre-Test and Post-Test Scores, Figure 2. Bland-Altman Plot of Pre-Test and Post-Test Scores

The validity tests showed variations in correlation between the 'Post' and 'Pre' items. Significant correlations between particular items show good validity, meaning they effectively measure the same aspects before and after the intervention or measurement period. However, some grains show low or insignificant correlations, suggesting that they may not measure the same

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construct or be inconsistent in their measurements. This indicates the need to evaluate these items further to ensure they provide valid and reliable measurements.

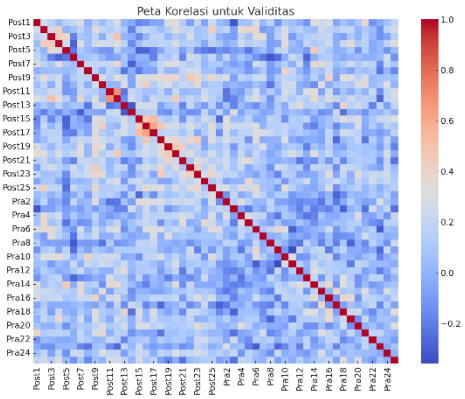

Figure 3. Correlation map for data validity

In research, item validity is crucial to ensure that the measurement instrument measures what is intended. Items with low validity can obscure the study results and lead to incorrect interpretation. Therefore, it is essential to revise or replace invalid items to improve the overall quality of the measuring instrument.

3.2. Reliability Test Explained

The 'Post' and 'Pre' reliability, measured using Cronbach's Alpha, showed mixed results. The reliability score for the 'Post' item (0.794) indicates a good level of reliability, which means that the responses given by respondents to these items are consistent over time. However, the reliability score for the 'Pre' item (0.423) is below the acceptable threshold, indicating low internal consistency. This implies that responses to the 'Pre' item may be inconsistent or influenced by external factors.

3.3. Normality Test Explained

The Shapiro-Wilk normality test results for 'PRA' and 'POST' scores showed that both data sets were normally distributed. A p-value greater than 0.05 (0.311 for 'PRA' and 0.528 for 'POST') indicates no sufficient reason to reject the normality hypothesis. The normal distribution is an important prerequisite for many parametric statistical tests, and its existence suggests that the use of advanced statistical techniques, such as paired t-tests, is reliable for these data.

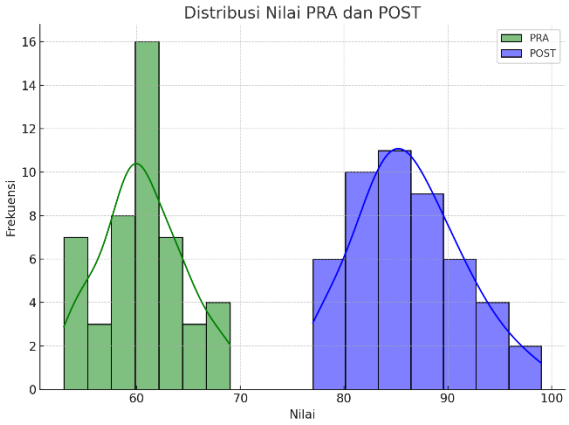

Figure 4. Distribution of Pre and Post-Test Scores

In the research context, data normality ensures that conclusions drawn from statistical tests are based on valid assumptions. The normal distribution of 'PRA' and 'POST' scores provides a solid basis for advanced statistical analysis. It shows that this study's sampling and measurement methods are pretty robust.

3.4. Homoscedasticity Test Explained

The homoscedasticity test with Levene's Test yielded a p-value of 0.122, indicating insufficient evidence to refute the hypothesis that the variance between 'PRA' and 'POST' scores was homogeneous. This uniformity of variance is necessary in statistical analysis, especially in t-tests that compare two related samples. Homoscedasticity provides additional confidence that the differences observed in paired t-tests are not due to uncontrolled variance differences.

In research, uniformity of variance between groups ensures that comparisons between 'PRA' and 'POST' scores are based on stable and consistent assumptions. This reinforces the validity of the statistical tests and ensures that conclusions drawn about differences or scores are on solid ground. Homoscedasticity also helps minimize distortions in parameter estimation and improve statistical inference accuracy.

3.5. Uji Paired T-test

The paired t-test produced a t-statistic value of -53.58 and a very small p-value (8.54 x 10^-44). This negative t-statistic value and a very small p-value significantly differ significantly between the 'PRA' and 'POST' scores. This difference is statistically and practically significant, given the difference's magnitude indicated by the t-statistic value. These results support the hypothesis that there were significant changes between conditions before and after, which may indicate the effectiveness of the intervention or the change measured by those items.

The paired t-test results, which yielded a t-statistic of -53.58 and a very small p-value (8.54 x 10^-44), indicate a highly significant difference between the 'PRE' and 'POST' scores. This difference is statistically and practically significant, as evidenced by the magnitude of the t-statistic. These results support the hypothesis that significant changes occurred between the conditions before and after, which may indicate the effectiveness of the intervention or change measured by these items.

In the context of this study, these results are crucial as they show that the variables measured in the study undergo significant changes. This could indicate that the process or intervention implemented between the 'PRE' and 'POST' scoring effectively achieves the intended goal. However, it is also essential to consider other factors that might influence these results, such as sample characteristics, the context of the intervention, or other external factors.

Relating these findings to the goals of the Teacher Professional Education (PPG) program in enhancing teachers' understanding of STEAM (Science et al.) education in the era of the Industrial Revolution 5.0 and Society 5.0, it can be concluded that the PPG program may have been successful in improving teachers' competencies in STEAM education. The significant changes in the 'PRE' and 'POST' scores suggest that the intervention or learning process within the program is effective. However, this success should be viewed as part of a broader context that includes supporting and hindering factors that may exist in the implementation of STEAM-based education.

Discussion

This study critically evaluates the effectiveness of Teacher Professional Education (PPG) Kindergarten education Teacher programs in enhancing the comprehension of STEAM education amidst the transformative forces of the Industrial Revolution 5.0 and Society 5.0. The initiative to integrate Science, Technology, Engineering, Arts, and Mathematics (STEAM) into pedagogical practice reflects a strategic response to the demands of modern educational frameworks, which prioritize cross-disciplinary skills and technological fluency. This integration facilitates a more dynamic learning environment conducive to developing the problem-solving and innovative capacities essential for the 21st century. Our research agenda is rooted in the hypothesis that well-structured professional development can profoundly impact teacher efficacy and instructional quality in STEAM education (Chuong et al., 2023; Lu et al., 2022). This hypothesis aligns with contemporary educational theories that emphasize the importance of adaptive learning environments and the role of educators in mediating complex knowledge in accessible ways.

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The outcomes of our validity and reliability tests and the analysis through paired t-tests provide compelling evidence of significant progress in teachers' competencies post-intervention. The markedly negative t-statistic and the extremely low p-value obtained from the paired t-test substantiate a significant enhancement in teachers' understanding and ability to implement STEAM methodologies effectively. Such results are statistically significant and hold practical relevance, indicating a substantial transfer of knowledge and skills during the PPG program (Chuong et al., 2023; Fernández, 2020; Gunawan et al., 2020; Guo et al., 2024; Quigley, 2020). These improvements suggest that the interventions within the program were robust, directly addressing the gaps in teachers' competencies and enhancing their instructional strategies in STEAM subjects.

Our findings resonate with existing literature that documents the positive impacts of structured professional development on teachers' pedagogical skills and self-efficacy, particularly in STEAM education (Jiang et al., 2023; Shyshenko et al., 2022). However, the variations in the 'Pre' reliability scores suggest inconsistencies that diverge from previous studies, which generally report improvements post-intervention. These discrepancies might be attributed to the pre-existing conditions or the specific characteristics of our sample, reflecting the nuanced challenges in implementing and measuring the efficacy of professional development programs. Such findings underscore the complexity of educational interventions and highlight the importance of context and initial assessment conditions in interpreting the outcomes of PD programs.

In line with studies highlighting the efficacy of innovative teaching methodologies, our research supports the benefits of flipped classrooms and design thinking, which significantly improve student engagement and learning autonomy (Guo et al., 2024; Zhang, 2023). Nonetheless, the initial low-reliability scores in our 'Pre' assessments contrast with findings from studies like those by Boulay et al. (2023), who report immediate improvements in teaching effectiveness following PD activities. This contrast may suggest the influence of initial assessment conditions or the unique context of our study, possibly indicating that our pre-intervention setup did not fully capture the initial competencies or the specific challenges faced by the participants.

The improvement in 'Post-test reliabilities and the normal distribution of scores post-intervention suggest that the PPG program successfully aligned with its educational objectives, promoting significant pedagogical shifts. These outcomes align with the broader educational goals of enhancing interdisciplinary understanding and applicability in teaching practices. However, the variability in the 'Pre' scores necessitates a cautious interpretation, suggesting that while the PPG program is effective, the foundational assessment tools and methodologies may require refinement to capture the complex dynamics of educational enhancements better (Surma et al., 2022; Zhao et al., 2022). This interpretation calls for a deeper investigation into how professional development impacts teaching efficacy, particularly in a multidisciplinary setting.

The variability observed in the initial test scores underlines the intricate nature of evaluating educational interventions and their outcomes. Though indicative of significant educational advancements, these results suggest that factors such as participant engagement, initial competency levels, and external educational conditions might have influenced the results. Such factors could mask the PPG program's direct impacts, making it challenging to delineate the effects of the intervention from those of external variables (Boice et al., 2021; Fenwick & Kelly, 2023; Petrila et al., 2022; Yakman & Lee, 2012). Therefore, a nuanced approach to data interpretation is warranted, emphasizing the need for ongoing assessment and adjustment to optimize the effectiveness of professional development in STEAM education.

The implications of this study extend beyond the immediate educational context, suggesting that well-structured PPG programs can significantly enhance teacher competency in STEAM education, aligning with the educational imperatives of the Industrial Revolution 5.0. These findings advocate for the strategic design and implementation of teacher development programs responsive to the evolving educational demands and capable of fostering an

interdisciplinary and technologically proficient teaching force. Policymakers and educational leaders should consider these insights in their ongoing efforts to refine and enhance professional development frameworks, ensuring they effectively address both the current and future needs of educators and students alike (Bamrungsin & Khampirat, 2022; Soodmand Afshar & Doosti, 2022). Such strategic focus is essential for sustaining educational innovations and for preparing educators to navigate and contribute to the complex landscapes of future learning environments.

Conclusion

This investigation primarily assessed the effectiveness of the Teacher Professional Education (PPG) Kindergarten education Teacher Program in enhancing teachers' comprehension of STEAM-based learning within the context of the Industrial Revolution 5.0 and Society 5.0. The findings substantiate that the PPG program likely improved pedagogical competencies relevant to STEAM education, as evidenced by significant differences in 'PRE' and 'POST' test scores. The paired t-test results, yielding a t-statistic of -53.58 and a p-value of 8.54 x 10^-44, demonstrate a highly significant difference between 'PRE' and 'POST' scores, supporting the effectiveness of the Teacher Professional Education (PPG) Kindergarten education Teacher program in enhancing STEAM competencies in the Industrial Revolution 5.0 era. This success, indicative of significant changes in the measured variables, suggests the effectiveness of the intervention. However, it must be contextualized within broader influencing factors like sample characteristics and the implementation environment. These results have pivotal implications for the advancement of STEAM education, suggesting that well-structured professional development programs can markedly bolster teacher competency. However, the study recognizes limitations such as the variance in the validity and reliability of test items and suggests future research should focus on refining assessment tools and exploring the longitudinal impact of training on teacher performance. The study reaffirms the critical role of targeted professional development in enhancing teacher competencies in STEAM disciplines, essential for educational alignment with the imperatives of the Industrial Revolution 5.0 while advocating for ongoing efforts to refine these programs and their evaluative metrics to realize their potential fully.

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