STEAM-Based Augmented Reality Media: Enhancing Gender-Responsive Pedagogy in Indonesian Early Childhood Education

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Abstract

This study aims to develop and evaluate STEAM-based Augmented Reality (AR) learning media to enhance teachers' competence in implementing gender-responsive pedagogy in early childhood education. Employing the ADDIE research and development model, the study involved 31 early childhood teachers in Walantaka District. The feasibility of the developed media was assessed by content experts, media experts, and practitioners, while its effectiveness was evaluated through pre- and post-test measures. The findings indicate that the AR-based learning media demonstrated very high feasibility, with an average validation score of 88% (ranging from 86% to 90%). The effectiveness analysis yielded an N-Gain score of 0.67, indicating a substantial improvement in teachers' competence in applying gender-responsive pedagogical practices. The developed media presents professional roles in a balanced and non-stereotypical manner and integrates STEAM principles to foster critical thinking, creativity, and problem-solving skills. The study concludes that STEAM-based AR learning media are effective in supporting the implementation of gender-responsive pedagogy in early childhood education. By embedding gender equality principles into immersive digital learning experiences, this research contributes to inclusive instructional design and provides educators with practical tools. Future studies are recommended to involve larger and more diverse samples, examine long-term impacts on classroom practices, and explore the integration of AR-based gender-responsive media across different educational contexts and learning domains.

Keywords: *Augmented Reality; Early Childhood Education; Gender Equality; Inclusive Pedagogy; STEAM*

A. INTRODUCTION

Early childhood education (ECE) plays a critical role in shaping children's early understandings of gender roles, making the creation of prejudice-free learning environments essential. However, within the context of Indonesian ECE, gender bias among teachers remains a persistent concern, reflected in the limited implementation of gender-responsive pedagogy and the continued use of biased instructional practices (Dianita, 2020; Utomo & Ekowati, 2019). This educational issue parallels broader patterns of gender inequality in Indonesia, including the underrepresentation of women in formal political and educational institutions (Firdaus & Wulandari, 2023; Rahayu & Ikayanti, 2014). Empirical evidence indicates that professional stereotypes and gender biases significantly shape classroom interactions, often directing children toward traditional gender roles from an early age (Losioki, 2023; Vu & Pham, 2022). At a global level, such inequalities are further reinforced by entrenched patriarchal cultures (Ko & Leung, 2025). Consequently, contemporary scholarship emphasizes the urgent need for pedagogical transformation toward more equitable and inclusive learning environments beginning in early childhood (Mthembu et al., 2023; Safa, 2025; Yuniawanti & Wulandari, 2025).

To address these challenges, a clear conceptual framework is required. Gender equality is commonly defined as the principle of fairness in the distribution of rights, responsibilities, and opportunities across genders (Eleanora & Sari, 2019). Within educational settings, this principle is operationalized through gender-responsive pedagogy, which functions as the practical mechanism for achieving equity. Gender-responsive pedagogy refers to an instructional approach that is sensitive to gender dynamics and ensures that all learners experience equitable participation free from discrimination (Kihwele et al., 2025; Mukagiahana et al., 2024; UNICEF, 2022). While gender equality represents the intended outcome, gender-responsive pedagogy provides the strategies necessary to translate this principle into daily classroom practices.

Alongside these conceptual considerations, digital innovation offers promising opportunities to support gender-responsive pedagogical practices. Augmented Reality (AR) has been shown to enhance learner engagement, motivation, and participation through its interactive and multimodal features (Kazlaris & Keramopoulos, 2025; Prasetya et al., 2024; Ruijia et al., 2025). Systematic reviews further suggest that AR applications in early childhood education support not only cognitive development but also social-emotional growth and collaborative learning experiences (Masmuzidin et al., 2022; Nirmala et al., 2024). In parallel, STEAM-based learning approaches are widely acknowledged for fostering creativity, critical thinking, and problem-solving skills among young children (Atikah & Biru, 2024; Filipe et al., 2024). Nevertheless, despite the growing body of research on STEAM and AR, gender equity is rarely positioned as a central design principle within STEAM-based AR learning media.

This gap is particularly significant in the Indonesian context, where deeply rooted patriarchal norms continue to shape educational practices. Preliminary observations conducted in Walantaka District reveal that classroom play activities are frequently segregated by gender, with constructive and technical play commonly assigned to boys, while

domestic and caregiving role-play is directed toward girls. Such practices reflect local cultural norms that reinforce traditional gender stereotypes and are compounded by the limited availability of instructional media designed to assist teachers in challenging and deconstructing these biases. Accordingly, the mere adoption of digital technology is insufficient; there is a pressing need for learning media that intentionally embed gender equity values within the STEAM framework.

Responding to this gap, the present study proposes the development of STEAM-based Augmented Reality learning media that explicitly integrate gender equity principles. This study aims to develop and validate STEAM-based AR media designed to promote gender equity in early childhood education, as well as to examine its effectiveness in enhancing teachers' competence in implementing gender-responsive pedagogy. Specifically, the research seeks to assess the feasibility of the developed media and to analyze the extent to which its use improves teachers' ability to apply gender-equitable practices in classroom settings.

B. METHOD

This study adopted a comprehensive methodological approach to empirically address the research questions concerning the feasibility and effectiveness of STEAM-based Augmented Reality (AR) media. The selected methodology was designed to ensure a systematic development process as well as a valid evaluation of the media's impact on the implementation of gender-responsive pedagogy. Accordingly, the following subsections describe the research design, development procedures, participants, instruments, and data analysis techniques employed in this study.

1. Research Design

This study employed a Research and Development (R&D) approach with the objective of developing STEAM-based Augmented Reality (AR) learning media that promote gender equality and examining its effectiveness in strengthening gender-responsive pedagogy (Creswell, 2012; Sugiyono, 2016). The development process followed the ADDIE model proposed by Branch, (2009), which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. This model was selected due to its structured and iterative nature, which supports both instructional design and educational media development. An overview of the research framework based on the ADDIE stages is presented in Figure 1.

Table 1. Product Assessment Criteria

Feasibility Percentage (%)	Feasibility Criteria	Description
0 – 20	Not Valid	Revision
21 – 40	Less Valid	Revision
41 – 60	Sufficiently Valid	Minor Revision
61 – 80	Valid	No Revision Needed
81 – 100	Highly Valid	No Revision Needed

2. Participants

The participants in this study were 31 early childhood education (ECE) teachers from Walantaka District, Serang City, Indonesia, selected using purposive sampling from institutions that had implemented STEAM-oriented learning approaches. The respondents held a Bachelor's degree (S1) in Early Childhood Education, with teaching experience ranging from 3 to 7 years and an age range of 25–45 years. This demographic profile was intentionally selected to ensure that participants possessed adequate pedagogical knowledge and professional experience to critically evaluate the developed AR-STEAM media and its pedagogical implications.

3. Procedures

The research procedures followed the five stages of the ADDIE development model. During the Analysis phase, needs assessment was conducted through field observations, surveys involving 31 ECE teachers, and a systematic literature review addressing gender bias in early childhood education and the use of digital learning media. Based on the identified needs, the Design phase involved the formulation of learning objectives and the development of instructional storyboards that integrated STEAM concepts with gender equality principles. In the Development phase, the AR-based media prototype was produced and subsequently validated by content experts, media experts, and language experts using a Likert-scale validation instrument (1–5). The validation process was conducted iteratively, with revisions implemented based on expert feedback until the media was deemed feasible for field testing. The Implementation phase consisted of a limited field trial employing a One-Group Pretest–Posttest Design. Although this design has inherent limitations related to internal validity when compared to control-group designs, it was considered appropriate for the preliminary testing stage of research and development. At this stage, the primary objective was to assess the sensitivity of the intervention and its direct instructional impact on the target user group prior to broader dissemination (Sugiyono, 2016). To minimize threats to internal validity, the intervention duration was standardized and the implementation procedures were kept consistent across all participants.

4. Data Collection Instruments

Data collection employed two main categories of instruments designed to evaluate both product quality and pedagogical effectiveness. The first category comprised validation and feasibility questionnaires administered to experts and teachers. These instruments assessed the media across three dimensions: (1) material aspects, including curriculum alignment, STEAM accuracy, and non-stereotypical representation; (2) media aspects, focusing on visual quality, usability, and AR interactivity; and (3) language aspects, examining clarity, appropriateness, and inclusiveness.

The second category consisted of effectiveness instruments designed to measure improvements in teachers' competence in implementing gender-responsive pedagogy. This instrument took the form of a pretest–posttest questionnaire developed around five indicators: gender awareness, inclusive language and communication, classroom

management, selection of non-stereotypical learning media, and objective assessment practices. To ensure data reliability, internal consistency was tested using Cronbach's Alpha, with a coefficient threshold of $\alpha = 0.70$ established as the criterion for acceptable reliability.

5. Data Analysis

The collected data were analyzed using a combination of descriptive and inferential statistics to ensure comprehensive evaluation. For the feasibility analysis, data derived from expert and teacher questionnaires were analyzed descriptively by calculating average scores, which were then converted into feasibility percentage categories ranging from Highly Valid to Not Valid. Regarding effectiveness analysis, the study employed rigorous statistical methods to address the limitations of the single-group design. The Normalized Gain (N-Gain) was first calculated to determine the magnitude of improvement in teacher competency. Furthermore, to statistically verify the significance of the difference between pretest and posttest scores, a Paired Sample t-test (or Wilcoxon Signed-Rank Test for non-normally distributed data) was conducted with a significance level of $p < 0.05$. This statistical rigor ensures that the observed changes are significant rather than coincidental, thereby strengthening the effectiveness claim despite the absence of a control group.

C. RESULT AND DISCUSSION
1. Result
a. Feasibility of the Developed Media

The feasibility of the developed STEAM-based Augmented Reality (AR) media was evaluated through expert validation involving material experts, media experts, and educational practitioners. The validation results indicate that the media falls within the Highly Feasible category, achieving an overall average score of 88%. This score reflects strong alignment with curriculum requirements, appropriate integration of STEAM concepts, non-stereotypical representations, and effective use of AR features. A detailed breakdown of feasibility scores from each expert group is presented in Table 1.

Table 1. Validation Results of AR-STEAM Gender Equality Learning Media

Validator	Feasibility Score (%)	Category
Material Expert	88	Highly Feasible
Media Expert	86	Highly Feasible
ECE Practitioner	90	Highly Feasible
Average	**88**	**Highly Feasible**

b. Implementation of STEAM Principles in AR Content

To ensure that the developed media effectively conveys gender equality, STEAM principles were explicitly embedded within the AR interactive modules. Each component was operationalized as follows:

1). **Science:** Users are encouraged to observe scientific phenomena related to various professions without gender bias, such as recognizing equal biological and cognitive capabilities between male and female medical professionals.

2). **Technology:** The core utilization of AR technology allows users to scan markers and visualize three-dimensional (3-D) professional avatars (e.g., a female pilot or a male chef), thereby creating an immersive and interactive digital learning experience.

3). **Engineering:** Interactive simulations allow users to design and construct professional environments, such as building a fire station or designing a bridge, emphasizing that technical and engineering skills are not gender-specific.

4). **Arts:** Inclusive visual designs and narratives are employed through diverse avatar characteristics, fostering empathy and challenging rigid visual stereotypes associated with masculinity and femininity.

5). **Mathematics:** Mathematical activities are integrated through tasks such as counting professional tools (e.g., stethoscopes or construction helmets) and grouping objects, reinforcing numeracy and logical thinking within a gender-balanced context.

This integrated implementation demonstrates that STEAM principles were not applied symbolically but functioned as a cohesive framework supporting gender-responsive learning experiences.

c. Effectiveness on Teacher Competence

The effectiveness of the AR-STEAM media in improving teachers' competence in implementing gender-responsive pedagogy was examined using a One-Group Pretest–Posttest Design involving 31 ECE teachers. The analysis comprised descriptive statistics, Normalized Gain (N-Gain) calculation, hypothesis testing, and reliability analysis.

d. Descriptive and N-Gain Analysis

The results reveal a substantial improvement in teacher competence following the intervention. The mean pretest score of 59.9 increased to 87.2 in the posttest. The calculated N-Gain score was 0.67, which falls within the medium-to-high effectiveness category. To illustrate the distribution of individual score improvements, Table 2 presents a scatterplot comparing pretest and posttest scores.

Table 2. Results of Paired t-test for Pretest and Posttest

Statistic	Value	Description
N	31	ECE Teachers
Mean Pretest	59,9	-
Mean Posttest	87,2	-
Selisih Mean (Posttest-Pretest)	27,3	-
t-calculated	23,84	-
Df	30	-
Sig. (2-tailed)	0,000	P<0,05

e. Hypothesis Testing

Prior to hypothesis testing, data normality was examined using the Shapiro–Wilk test, which indicated that the data were normally distributed ($p > 0.05$). Accordingly, a Paired Sample t-test was conducted to examine the significance of score differences. The results, summarized in Table 2, show a significance value of 0.000 ($p < 0.05$) and a calculated t value of 23.84. These findings confirm a statistically significant difference between pretest and posttest scores, indicating that the AR-STEAM media effectively enhanced teachers' competence in applying gender-responsive pedagogy.

f. Reliability Analysis

The reliability of the research instruments was assessed using Cronbach's Alpha. The expert validation questionnaire achieved a reliability coefficient of 0.86, while the teacher response questionnaire yielded a coefficient of 0.91. With an overall average reliability of 0.89 ($\alpha > 0.70$), the instruments are confirmed to possess high internal consistency and reliability.

2. Discussion

a. The Mechanism of Change: Integrating AR, STEAM, and Gender Pedagogy

The empirical findings of this study substantiate that the developed AR-STEAM media is highly effective in improving ECE teachers' competence in gender-responsive pedagogy, as indicated by the medium-to-high N-Gain score of 0.67. Beyond statistical improvement, this study contributes a conceptual explanation of how such change occurs by proposing a mechanism in which AR technology, STEAM pedagogy, and gender-responsive principles interact to challenge and reconstruct teachers' gender perceptions.

Previous international studies have independently documented the benefits of STEAM approaches in fostering creativity, problem-solving, and higher-order thinking (Ameh et al., 2025); Gu et al., 2023), as well as the potential of digital learning media to support inclusive educational practices (López et al., 2025; Navas-Bonilla et al., 2025). However, these studies rarely explicate the psychological process through which digital media facilitates the internalization of gender-equitable values among educators. This study extends the literature by identifying a specific mechanism of change, conceptualized as *embodied cognitive dissonance* (Harmon-jones, 2017; Kaaronen, 2018).

Gender bias among teachers often operates at an implicit and subconscious level, embedded within long-standing cultural schemas and everyday pedagogical routines. Through immersive AR experiences, teachers are directly exposed to visual counter-narratives, such as representations of female firefighters or male nurses, that contradict traditional gender stereotypes. This confrontation between existing mental schemas and novel visual stimuli generates cognitive dissonance—a psychological state that motivates individuals to resolve inconsistency between beliefs and experiences (Zhang & Juvrud, 2024). In this context, AR functions not merely as a visualization tool, but as an experiential medium that destabilizes stereotypical assumptions.

Unlike conventional training methods that rely on textual explanations or lectures, the interactive nature of AR enables embodied learning, where users actively engage with and manipulate non-stereotypical representations. As highlighted by Radu et al. (2023) and Salamah et al. (2024), such embodied interaction enhances attention, emotional engagement, and meaning-making processes. This immersive engagement amplifies the dissonance effect, making gender bias more visible and cognitively salient to teachers.

Furthermore, the integration of STEAM principles further strengthens this transformation by shifting the pedagogical focus from gendered identities to demonstrated competencies. Engineering and scientific simulations embedded in the media require logical reasoning, creativity, and collaboration, thereby emphasizing performance-based achievement rather than sex-based role expectations (Dominguez & Castells, 2025; Rantanen et al., 2025). Through repeated exposure to these competence-oriented tasks, teachers experience firsthand that technical and problem-solving abilities are inherently gender-neutral.

The integration of STEAM principles within instructional media design aligns with evidence that educators who adopt STEAM approaches grounded in project-based methods demonstrate greater competence in facilitating interdisciplinary and exploratory learning. Research on STEAM implementation using loose parts indicates that such pedagogical frameworks enable teachers to create learning experiences that support holistic development by engaging children in scientific inquiry, creative construction, and applied problem solving (Amri et al., 2024). This supports the notion that STEAM-oriented digital tools, like the developed AR media, have a strong pedagogical basis for enhancing both teacher practice and children's access to integrative and inclusive learning opportunities.

Collectively, these processes translate the abstract notion of gender equality into a concrete, experiential, and internalized pedagogical value. The AR-STEAM media thus functions as a bridge between theoretical understanding and practical classroom implementation, enabling teachers to reconceptualize gender roles and apply gender-responsive pedagogy more consistently in early childhood learning environments.

b. Policy Implications and Practical Recommendations

The positive impact of the developed AR-STEAM media aligns closely with national education policies, particularly the Regulation of the Minister of National Education No. 70 of 2009 concerning inclusive education, which emphasizes the provision of equitable learning opportunities for all children. While such policies provide an important normative framework, their implementation in everyday classroom practice often remains inconsistent. Addressing this gap, the present study offers several practical recommendations aimed at translating policy mandates into actionable pedagogical strategies.

At the policy level, it is recommended that the Ministry of Education, Culture, Research, and Technology, in collaboration with Teacher Education Institutions,

formally integrate gender-responsive AR-STEAM learning media into the Teacher Professional Education curriculum. Embedding such media within pre-service teacher training would function as a preventive and formative intervention, enabling future teachers to critically reflect on and deconstruct gender biases before entering professional practice (Musthofa et al., 2024). This integration would serve as a systematic intervention to deconstruct biases among pre-service teachers before they enter the workforce.

To promote equitable access, the integration of AR-based gender-responsive learning modules into the *Merdeka Mengajar* digital platform is also strongly recommended. This strategy would enable teachers in geographically remote or under-resourced areas to access high-quality, inclusive instructional media, thereby reducing disparities in professional development opportunities. At the institutional level, early childhood education centers are encouraged to systematically incorporate Gender-STEAM activities into their operational curricula. Such integration would help dismantle gender-based segregation in play and learning areas, ensuring that activities such as block play, science exploration, and role-play are accessible to all children regardless of gender (Am et al., 2025; Kao et al., 2025; Lunga et al., 2022).

Beyond the national context, these policy and practice-oriented initiatives contribute directly to the achievement of Sustainable Development Goal (SDG) 5 on Gender Equality (United Nations, 2015). By embedding gender equity principles within early childhood pedagogy through innovative digital media, Indonesia positions itself as an active contributor to global efforts aimed at preventing the reproduction of patriarchal stereotypes from an early age and fostering more inclusive educational systems.

c. Limitations and Future Directions

Despite the promising findings, this study has several limitations that warrant careful consideration. First, the relatively small sample size of 31 early childhood education teachers and the specific focus on Walantaka District limit the generalizability of the results. Although the feasibility and effectiveness analyses yielded high scores and statistically significant outcomes, these findings primarily reflect the internal validity of the intervention within a localized context. Consequently, caution is required when extrapolating the results to broader national or international settings.

Nevertheless, the consistently high feasibility ratings provided by material, media, and practitioner validators indicate that the design quality and pedagogical content of the AR-STEAM media possess strong potential for transferability. While the statistical outcomes are sample-specific, the underlying pedagogical mechanisms, particularly the media's capacity to challenge and reconstruct gender stereotypes through immersive and competence-based learning, are likely applicable in contexts with similar cultural and educational characteristics.

To strengthen external validity and empirical robustness, future research is strongly encouraged to adopt multi-center study designs involving diverse geographical

regions and sociocultural settings across Indonesia. In addition, the use of quasi-experimental or experimental designs incorporating control groups would enable a more rigorous examination of the causal effects of AR-based media on teachers' gender-responsive pedagogical competence. Longitudinal studies are also recommended to assess the sustainability of learning outcomes and the long-term retention of attitudinal and pedagogical change. Such methodological expansions would provide a stronger evidence base to support large-scale implementation and policy adoption of gender-responsive AR-STEAM media in early childhood education.

D. CONCLUSION

This study confirms that STEAM-based Augmented Reality (AR) media effectively enhances early childhood education teachers' competence in implementing gender-responsive pedagogy. The findings extend existing literature by positioning AR not only as a tool for cognitive development, but also as a medium for social reconstruction that can challenge and reframe entrenched gender stereotypes through immersive, competence-oriented learning experiences. Practically, the developed media supports inclusive teaching practices and critical reflection, enabling teachers to translate abstract principles of gender equality into concrete classroom actions aligned with the *Merdeka Belajar* (Freedom to Learn) framework.

From a policy perspective, the results highlight the strategic importance of integrating gender-responsive digital learning media into national early childhood education initiatives, including Holistic Integrative ECE, as part of Indonesia's commitment to Sustainable Development Goals (SDGs) 4 and 5. Future research should investigate the direct impact of such media on children's perceptions of social and professional roles, as well as explore its systematic integration into national curricula and teacher professional development programs to support large-scale and sustainable implementation.

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