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Research Synthesis Reports as Pedagogical Scaffolds: A Constructive Alignment Study in Doctoral Science Education

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ABSTRACT: Doctoral students in the field of science education frequently find it challenging to effectively summarize a large volume of academic research and pinpoint genuine areas where more study is needed, which can result in poorly defined research problems and a lack of originality in their work. This study looks into how research synthesis reports can serve as a supportive teaching strategy within an Outcome-Based Education framework. A Design-Based Research (DBR) method was carried out, involving 20 doctoral students, in a project-based learning setting that integrated STEAM disciplines and utilized Artificial Intelligence (AI) systems that were developed with ethical considerations in mind. Data were gathered using a pretest and posttest approach, standardized project rubrics, and analytics related to AI usage. The results show a notable increase in research literacy, indicated by an N-gain score of 0.72, which falls into the high category, and also show consistently strong performance across the different parts of the dissertation proposal. These findings indicate that research synthesis reports serve as a useful framework for improving the logical structure of research and strengthening the reasoning process used in methodological approaches. This research adds to the increasing understanding of AI-supported teaching methods for doctoral programs and offers evidence-based support for incorporating structured scaffolding approaches in education based on outcomes-based learning.

KEYWORDS: science education, doctoral education, research synthesis, outcome-based education, STEAM, artificial intelligence

INTRODUCTION

Doctoral education represents the pinnacle of academic training, tasked with producing scholars capable of generating original knowledge and addressing complex societal challenges (McKenney & Reeves, 2019; Sarrico et al., 2022). In the field of science education, this responsibility is increasingly aligned with global agendas such as SDG 4 (Quality Education) and SDG 13 (Climate Action), requiring candidates to demonstrate not only methodological rigor but also advanced synthesis capabilities (Tight, 2018; Yang et al., 2025).

However, the rapid expansion of scientific publications—often described as the "information explosion"—has significantly complicated the process of identifying authentic research gaps (Page et al., 2021; Ngulube, 2023). Even at the doctoral level, many candidates struggle to critically evaluate and position their work within broader scholarly discourse, reflecting a lack of epistemic agency (Asamoah & Amarteifio, 2025). This condition frequently results in weak problem formulation and limited research novelty.

In Indonesia, this challenge is further situated within a systemic transformation in higher education following the enactment of Permendiktisaintek No. 39 Tahun 2025 (Kemendiktisaintek, 2025), which mandates the adoption of Outcome-Based Education (OBE). This paradigm emphasizes measurable learning outcomes, adaptive curricula, and the integration of digital innovation to enhance educational quality (UNESCO, 2020; Haningsih & Rohmi, 2022). Within this framework, doctoral education is expected to produce graduates capable of generating impactful, evidence-based research aligned with national and global standards.

Despite these policy advancements, there remains a critical gap between expectations and actual doctoral student competencies, particularly in synthesizing literature and constructing coherent research frameworks. Therefore, this study aims to examine the effectiveness of research synthesis reports as pedagogical scaffolding within an OBE-based doctoral learning environment, integrating STEAM perspectives and ethically guided Artificial Intelligence (AI) to enhance research literacy and methodological reasoning.

LITERATURE REVIEW

Doctoral education is the highest level of academic training, designed to develop researchers who can create new knowledge and tackle difficult issues facing society (McKenney & Reeves, 2019; Sarrico et al., 2022). In the field of science education, this responsibility is becoming more

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closely connected with global goals like SDG 4 (Quality Education) and SDG 13 (Climate Action). As a result, candidates are expected to show not just strong research skills but also the ability to combine and understand complex information effectively (Tight, 2018; Yang et al., 2025).
However, the quick growth of scientific publications, which is often referred to as the "information explosion," has made it much harder to find real research gaps (Page et al., 2021; Ngulube, 2023). Even at the doctoral level, many candidates find it challenging to critically assess and place their work within the wider academic conversation, which shows a limited ability to take control of their knowledge and understanding (Asamoah & Amarteifio, 2025). This condition often leads to poorly defined problems and a lack of originality in research.
In Indonesia, this challenge occurs within a broader systemic transformation in higher education, as outlined by Permendiktisaintek No. 39 Tahun 2025 (Kemendiktisaintek, 2025), which requires the implementation of Outcome-Based Education (OBE). This approach focuses on clear learning results, flexible course designs, and the use of digital tools to improve the effectiveness of education (UNESCO, 2020; Haningsih & Rohmi, 2022). Within this structure, doctoral programs aim to develop graduates who can create research that is both meaningful and supported by evidence, meeting the standards set at the national and international levels.
Even though there have been improvements in policies, there is still a significant difference between what is expected of doctoral students and their actual abilities, especially when it comes to combining existing research and building clear research structures. This study seeks to investigate how research synthesis reports can serve as supportive structures in a doctoral learning environment that is based on outcomes-based education, while incorporating STEAM perspectives and ethically informed Artificial Intelligence to improve research literacy and the ability to reason about research methods.

MATERIALS AND METHODS

This study adopted a Design-Based Research (DBR) framework (Scott, 2021), structured into three iterative phases as described in Table 1

Table 1. Iterative Phases of the Design-Based Research (DBR) Framework

Phase	Core Pedagogical Activities	Objective and Output
1. Analysis & Exploration	Assessment of doctoral students' synthesis literacy; exploration of research artifacts (PRISMA reports) as scaffolds (Mckenney & Reeves, 2019).	Identification of literacy gaps; formation of initial design principles.
2. Design & Construction	Development of the OBE–PBL–STEAM–AI curriculum; creation of "worked examples" from authentic research artifacts (Page et al., 2021).	Prototype of the instructional intervention; aligned Sub-CPMK (Biggs et al., 2022).
3. Evaluation & Reflection	Implementation in a doctoral course; triangulation of data (Pretest-Posttest, Rubrics, AI Logs) (Krajcik & Shin, 2022).	Evaluation of student learning gains (N-gain); refinement of design principles.

DBR was selected because it allows for the development of practical solutions while simultaneously refining instructional theories.

Research Context and Participant Characteristics

The intervention involved 20 doctoral students in the Science Education program at Universitas Negeri Semarang (UNNES) during the 2025 academic year. The "Science Education Research Methods" course served as the site for the intervention, delivered via a blended learning format that combined synchronous seminars with asynchronous project-based tasks. Participants were selected through purposive sampling, as they were at a critical stage of dissertation proposal development and possessed diverse professional backgrounds. Table 2 provides a detailed profile of the demographic and academic characteristics of the participants involved in this study.

Table 2. The demographic and academic characteristics of the participants

Profile Category	Characteristic Description	Distribution / Frequency	Initial Literacy Status
Educational Background	Master of Physics, Biology, Chemistry, or General Science Education.	20 Students (100%)	Moderate (Mean: 58.50)
Professional Role	University Lecturers (80%), Others (20%).	16 Lecturers, 4 Teachers and fresh graduate of a master's program	Varied field research experience.
Previous Research Exp.	Published at least one article in an national journal.	18 Students (90%)	Established scientific writing basics.
Digital Literacy	Familiar with Google Scholar; limited bibliometric proficiency.	20 Students (100%)	Requires training in ethical AI and VOSviewer.
Dissertation Focus	Development of Media, Learning Strategies, or Science Curriculum.	100% Science Oriented	Requires STEAM framework integration.
Academic Motivation	Aiming to complete doctoral studies within 6 semesters.	Very High	Focused on synthesis efficiency.

Participant profiles indicate that while they are experienced educational practitioners, there is a significant need to improve their capacity for systematic and deep literature synthesis. Most students enter the doctoral program with procedural research understanding but lack the epistemic reasoning required to connect diverse research findings into a coherent narrative (Ngulube, 2023). The inclusion of Table 2 is vital in DBR, as target audience characteristics determine how scaffolding must be designed (Kamler & Thomson, 2021; McKenney & Reeves, 2019).

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Instructional Framework: Constructive Alignment

The curriculum was built on a "designing back" philosophy called backward design (Wiggins & McTighe, 2005), mapping specific learning activities to intended outcomes, as can be seen in Table 3.

Table 3. Constructive Alignment of the Instructional Framework

Intended Learning Outcome	Teaching and Learning Activities (TLAs)	Assessment Tasks (ATs)
Synthesize research trends using PRISMA logic (Page et al., 2021).	Scaffolding with research synthesis artifacts; bibliometric mapping workshop .	Research Trend Portfolio; PRISMA Flow Diagram (Page et al., 2021) .
Formulate STEAM-oriented research problems (Spyropoulou & Kameas, 2025).	Sustainability inquiry (SDG 13); interdisciplinary case study analysis. (Sipos, 2020)	Dissertation Proposal Part A: Problem Formulation (Krajcik, & Shin, 2022).
Integrate AI as an ethical cognitive support (Asamoah & Amarteifio, 2025).	AI prompt engineering; human-verification of AI-generated summaries.	AI Usage Log & Reflective Portfolio (Chan, 2024).

Data Collection and Analysis

To ensure validity, a mixed-methods approach was implemented using the matrix shown in Table 4.

Table 4. Data Collection and Analysis Matrix

Source of Evidence	validated Instrument	Analytical Method	Purpose
Quantitative	Assessment Literacy Inventory (ALI)	Descriptive statistics & *N*-gain.	Measuring gains in synthesis literacy.
Performance	Project Rubrics (Proposal Components)	Assurance of Learning (AoL) Analysis	Evaluating achievement of intended learning outcome.
Qualitative	AI Logs & Reflective Portfolios	Thematic Analysis	Identifying patterns of ethical AI use.
Perception	5-Point Likert Questionnaire	Cronbach's α calculation	Assessing instructional relevance.

RESULTS

Quantitative Results: Research Literacy Gains

Pretest results showed a moderate baseline in research literacy (M = 58.50). After the intervention, posttest scores increased significantly (M = 88.40), yielding a high *N*-gain of 0.72 (Yang et al., 2025).

Table 5. Pretest-Posttest Literacy Gain

Assessment Category		Pretest Mean (SD)	Posttest Mean (SD)	N-gain	Category
Research Trend Literacy		58.50 (5.2)	88.40 (4.8)	0.72	High

Performance Results: Assurance of Learning (AoL)

Analysis of Assurance of Learning (AoL) confirmed that all 20 students achieved the Excellent threshold, reflecting full achievement of the intended outcomes and the effectiveness of the OBE framework in exceeding national standards defined by Permendiktisaintek 39/2025. The findings support the notion that using research synthesis reports as pedagogical artifacts reduces cognitive load. A comparison between Traditional Review and Artifact-based Scaffolding is presented in the Table 6.

Table 6. Comparison: Traditional Review vs. Artifact-based Scaffolding

Dimension	Traditional Literature Review	Artifact-based Scaffolding (Proposed)	Theoretical Foundation
Cognitive Load	High (Trial and Error)	Managed (Worked Examples)	Sweller & Kirschner.
Epistemic Access	Limited to procedure.	Deep engagement with evidence clusters.	Epistemic Apprenticeship.
Synthesis Rigor	Variable quality.	Systematically aligned with PRISMA.	Scaffolding Theory.

Qualitative Result: AI Usage Patterns

Analysis of AI logs provided insights into how doctoral candidates utilized generative tools without compromising integrity. The systematic approach to AI integration, characterized by meticulous human-in-the-loop verification, is detailed in Table 7.

Table 7. Patterns of Ethical AI Use and Verification

AI Task Category	% Students	Human-Verification Strategy	Academic Integrity Result
Search Optimization	85%	Cross-checking citations in Publish or Perish.	100% Valid
Synthesis Support	70%	Fact-checking summaries against primary PDFs.	100% Valid
Methodological Check	40%	Aligning AI suggestions with PRISMA 2020 items.	100% Valid

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Analysis of AI logs indicated that students primarily used AI for search query optimization (85%) and summarization (70%). Participants demonstrated strong epistemic responsibility by verifying all AI outputs against primary sources. These behavioral patterns are reflected in the students' academic performance, as summarized in Table 8.

Table 8. Achievement Level Based on Assurance of Learning (AoL)

Mastery Level	Criteria (Score)	Percentage of Students	Alignment Status
Excellent	≥ 85	100%	Full Alignment
Satisfactory	70 - 84	0%	-
Underperforming	< 70	0%	-

All 20 students achieved the "Excellent" status, meeting standard exceedance requirements.

Qualitative Result: Constructive Alignment as a Mechanism for Improving Doctoral Learning Outcomes

Another important finding of this study is the successful implementation of constructive alignment within the doctoral research methods course. All participants achieved the “Excellent” mastery level according to the Assurance of Learning (AoL) evaluation, indicating that the alignment between intended learning outcomes, teaching-learning activities, and assessment tasks effectively supported students’ academic development.

This study provides a concrete model for implementing Permendiktisaintek No. 39 Tahun 2025. The synergy between the pedagogical interventions and the mandate of the national policy is summarized in the Table 9.

Table 9. Alignment of Interventions with National Policy Indicators

Permendiktisaintek 39/2025 Indicator	Instructional Strategy Employed	Alignment Result
Outcome-Based Education (OBE).	Full Constructive Alignment of TLAs and ATs.	Highly Aligned.
Standard Exceedance.	Achievement of "Terakreditasi Unggul" via AoL.	Exceeded Minimum.
Technology-Enhanced Learning.	Responsible GenAI & Bibliometric Analytics.	Future-Ready.

Perception Results: Instructional Evaluation

Results from the 5-point Likert questionnaire indicated a high level of perceived instructional relevance and usability of research synthesis reports. Reliability analysis showed that the instrument achieved acceptable internal consistency (Cronbach’s $\alpha \geq 0.80$), indicating that the perception data were statistically reliable and suitable for interpretation. Importantly, the perception results also reflect students’ positive responses to the integration of STEAM-based learning within the instructional framework. Students perceived the learning experience as more meaningful and engaging due to its interdisciplinary nature, which connected research synthesis activities with broader real-world contexts, including sustainability-related issues aligned with SDG 4 and SDG 13.

Students demonstrated high proficiency in synthesizing interdisciplinary connections, a skill essential for solving complex environmental challenges . Moreover, the ethical integration of Artificial Intelligence (AI) as bounded cognitive support proved critical for modern doctoral workflows. By requiring prompt logs and human-verification, the course fostered epistemic responsibility, ensuring that technological efficiency did not undermine academic integrity . This critical AI literacy is a vital competency for researchers in the Society 5.0 era, where human-centered innovation must be balanced with ethical rigor. The synthesis of these integrated elements is detailed in Table 10.

Table 10. Synthesis of STEAM-AI Integration for SDG 13

Component	Pedagogical Implementation	Contribution to Research Competence
STEAM	Integration of action-oriented action (SDG 13).	Interdisciplinary problem-solving.
Artificial Intelligence	Bounded support for evidence mapping.	Critical AI Literacy.
Social Responsibility	Ethical research conduct & ESD.	Epistemic Responsibility.

DISCUSSION

Quantitative Gains and Assurance of Learning (AoL)

The findings of this study demonstrate that the integration of research synthesis reports as pedagogical artifacts significantly improves doctoral students’ research literacy, particularly in identifying research trends and formulating authentic research gaps. The substantial increase in research literacy scores, reflected in the high N-gain value (0.72), indicates that the instructional intervention effectively enhanced students’ analytical and synthesis competencies required for doctoral-level research. This improvement suggests that structured scaffolding strategies can support doctoral students in navigating complex scientific literature and constructing evidence-based research problems.

The results demonstrate that the research synthesis report (Ridlo et al., 2024) functioned as a powerful pedagogical artifact (Tight, 2018). By engaging with identified thematic clusters, students transitioned from surface reading to bibliometric reasoning, identifying authentic gaps that traditional reviews often overlook (Borrego, Foster, & Froyd, 2019). This aligns with the epistemic apprenticeship model, where learners develop expertise by participating in authentic scholarly practices.

From a cognitive learning perspective, these findings can be explained through scaffolding theory, which suggests that learners perform complex intellectual tasks more effectively when provided with structured guidance and gradually released responsibility (Doo et al., 2021; Ghani et al., 2021; Pradhan, 2021). Problem-Based Learning promotes deep conceptual understanding and self-regulated learning through authentic problem solving (Yew & Goh, 2016). Recent systematic reviews further confirm that PBL enhances critical thinking, academic performance, and self-

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regulated learning across educational contexts (Ghani et al., 2021; Guo et al., 2024). Doctoral research training often requires students to synthesize extensive literature, evaluate methodological trends, and identify conceptual gaps within their research field. Without adequate scaffolding, many students experience cognitive overload due to the complexity and volume of scholarly information. The use of research synthesis reports as pedagogical artifacts therefore serves as an effective cognitive support mechanism by providing students with structured models of literature synthesis.

This finding is also consistent with cognitive load theory, which emphasizes that well-designed instructional scaffolds can reduce unnecessary cognitive burden and allow learners to focus on higher-order thinking processes (Makransky & Petersen, 2021; Paas & van Merriënboer, 2020; Sweller et al,, 2011). In the context of doctoral education, research synthesis reports function as worked example that illustrate how systematic literature reviews and bibliometric analyses are conducted. By examining these artifacts, students can observe the logic of research synthesis, enabling them to develop methodological reasoning and analytical skills more efficiently.

Moreover, the results of this study support the concept of epistemic apprenticeship, which emphasizes that advanced academic skills are best developed through participation in authentic scholarly practices (Greene, 2016). Rather than learning research methods solely through theoretical instruction, students engaged directly with real research artifacts, allowing them to experience the processes of knowledge synthesis and gap identification. This form of learning aligns with contemporary approaches to doctoral education that emphasize experiential and inquiry-based learning.

The effectiveness of artifact-based scaffolding observed in this study is also supported by previous research in graduate education. Borrego et al. (2019) reported that structured literature review frameworks significantly enhance graduate students' ability to synthesize research evidence and identify methodological trends. Similarly, McKenney and Reeves (2019) highlighted that design-based learning environments supported by authentic research materials can strengthen students' research competence. The present study extends these findings by demonstrating that research synthesis reports can serve not only as scholarly outputs but also as pedagogical tools for doctoral training.

Constructive Alignment, Ethical AI Integration and STEAM Integration

Constructive alignment theory posits that effective learning occurs when instructional design ensures coherence between learning objectives, teaching strategies, and assessment methods (Biggs, 1966; Biggs et al., 2022). In this study, the course design aligned the learning outcomes of research synthesis and problem formulation with artifact-based learning activities and project-based assessments. This alignment ensured that students were consistently engaged in tasks that directly contributed to the achievement of the intended competencies.

The findings of this study are consistent with previous research on outcome-based education (OBE). Pradhan (2021) demonstrated that learning environments structured around outcome-based principles significantly improve students' cognitive engagement and academic achievement. Similarly, Tight (2018) observed that modern doctoral programs increasingly emphasize competency-based learning models that focus on research productivity and scholarly impact.

The present study contributes to the literature by illustrating how constructive alignment can be operationalized in doctoral research methodology courses through the integration of authentic research artifacts. This approach ensures that students not only acquire theoretical knowledge about research methods but also develop practical skills in literature synthesis, research design, and academic reasoning.

Furthermore, the implementation of constructive alignment in this study also supports institutional quality assurance frameworks in higher education. By linking course outcomes with measurable performance indicators, doctoral programs can ensure that students achieve competencies aligned with national and international academic standards.

The integration of Artificial Intelligence (AI) tools as bounded cognitive support represents another significant dimension of the instructional intervention. The analysis of AI usage logs revealed that students primarily used generative AI for literature search optimization and summarization tasks while maintaining rigorous verification of AI-generated outputs.

These findings correspond with recent discussions on the role of AI in academic research. AI technologies have increasingly been used to support information retrieval, knowledge mapping, and research synthesis processes (Fu & Weng, 2024). When used responsibly, these tools can significantly improve research efficiency by enabling scholars to identify relevant literature more quickly and organize complex information more systematically.

However, scholars have also emphasized the importance of maintaining ethical standards in AI-assisted research practices. Miao and Holmes (2023) highlight that generative AI should function as a supportive cognitive tool rather than a replacement for human intellectual reasoning. Similarly, Zhu et al. (2025) argue that responsible AI use in education requires transparency, verification, and critical evaluation of AI outputs.

The present study demonstrates that ethical AI integration can be achieved by implementing structured verification mechanisms such as prompt documentation and source validation. This approach promotes critical AI literacy, enabling doctoral students to use AI technologies effectively while maintaining academic integrity (Bridges et al., 2025). As digital research tools continue to evolve, the development of such competencies will become increasingly essential for future scholars.

The findings of this study offer several important implications for doctoral education and research training. First, the use of research synthesis reports as pedagogical scaffolds provides an effective strategy for addressing one of the most common challenges faced by doctoral students: identifying authentic research gaps. The rapid growth of scientific publications has made it increasingly difficult for researchers to navigate the vast body of existing knowledge (Page et al., 2021). Structured synthesis artifacts can therefore serve as cognitive maps that help students understand research trends and identify opportunities for innovation.

Second, the integration of STEAM perspectives encourages interdisciplinary thinking in research design. Contemporary scientific challenges such as climate change, technological transformation, and sustainable development require collaborative and cross-disciplinary approaches (Bascopé et al., 2019). By incorporating STEAM frameworks into doctoral research training, universities can prepare scholars to address complex societal problems (Amanova et al., 2025).

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Third, the incorporation of AI-assisted research tools highlights the growing importance of digital research literacy in higher education. As academic research increasingly relies on digital infrastructures and data-driven knowledge analysis, doctoral programs must equip students with skills for responsible technology use and information management.

CONCLUSION

This study concludes that utilizing research synthesis reports as pedagogical scaffolds significantly enhances doctoral research competence. The alignment of OBE, PBL, STEAM, and ethical AI use supports candidates in designing research that is systematic and evidence-based. This model offers a blueprint for doctoral programs seeking to meet the quality standards of Indonesian and international higher education.

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