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Integrating STEM Learning and the RSD Framework to Enhance Research Skills: Evidence from a Quasi-Experimental Study in Science Education

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ABSTRACT

This study evaluates the impact of a STEM-based science learning model integrated with the Research Skill Development (RSD) framework on students' research capabilities. Using a quasi-experimental pretest-posttest design, the study compared an experimental group and a control group of 120 third-semester science education students to determine the effectiveness of the intervention relative to project-based learning. The instrument used was a research skills test based on the RSD framework, covering stages from problem formulation to data analysis. Results indicate that the experimental cohort achieved superior performance compared to the control group in the post-intervention evaluations. This significant divergence was validated by an independent t-test ($t = 8.25$, $p < 0.05$), confirming the statistical weight of the findings. These results imply that merging STEM with the RSD framework fosters a systematic environment that enhances research competencies, specifically in hypothesis generation, data management, and analytical thinking. Consequently, this research offers robust empirical support for the adoption of integrated STEM-RSD models in higher education. It highlights its potential for preparing students with essential research competencies for academic and professional contexts.

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1. INTRODUCTION

Research skills are one of the most important competencies in the modern era, particularly in higher education, as they enable students to generate knowledge, analyse data and solve complex problems (Gerstein & Friedman, 2016). In science, these skills not only support the theoretical understanding of concepts but also directly engage students in authentic scientific processes (Setiawan et al., 2017). However, various empirical findings indicate that students' research abilities remain relatively low. For example, Willison & Buisman-Pijlman (2016) state that undergraduate students still face difficulties in formulating research problems independently and critically evaluating evidence, particularly in the early stages of research skill development. In line with this, research by Mataniari et al. (2020) indicates that the majority of students remain at a low level within the Research Skill Development (RSD) framework, characterised by limitations in data analysis and the interpretation of research findings. This situation is inextricably linked to the dominance of less structured learning approaches that do not explicitly support RSD in higher education, which tend to focus on the delivery of material through lectures, thereby failing to provide sufficient scope for students to engage actively in the process of inquiry and research (Khasawneh, 2016). Consequently, students' opportunities to develop higher-order thinking skills and independent research abilities are limited, resulting in a gap between expected competencies and students' actual achievements.

The main problem faced by students is the limited opportunity to engage in learning activities that encourage direct involvement in the research process. The learning process in higher education is still dominated by an approach that focuses on mastering subject matter and theory, without providing adequate experience in real-world application (Winget & Persky, 2022). Consequently, many students graduate from science programmes with suboptimal research skills. Empirical findings indicate that the majority of students remain at a low to intermediate level of research proficiency, particularly in the areas of data analysis and interpretation of results. Research by Hidayat et al. (2024) suggests that students' analytical thinking skills within the STEM context have not yet developed to their full potential. Meanwhile, research by Malik & Zhu (2023) found that without project-based learning interventions, improvements in higher-order thinking and research skills tend to be limited. This situation highlights a gap between the competency requirements for graduates and students' actual achievements. However, skills such as data analysis, critical thinking, and problem-solving are vital in the workplace and form the cornerstone of academic career development (Li, 2022).

The STEM approach is widely regarded as a vital tool for enhancing students' research and critical thinking skills (Fajrina et al., 2020). Its strength lies in integrating various disciplines, enabling students to address complex challenges through a comprehensive lens (Dare et al., 2021). However, in Indonesia, the application of STEM has not been widely adopted, especially in higher education. Empirical data shows that even at school level, around 54.5% of science teachers in Indonesia have never implemented a STEM approach in their teaching, indicating a generally low level of adoption. Furthermore, research in Indonesia also indicates that the implementation of STEM education remains limited to specific contexts and has not yet been systematically integrated into teaching or research processes at higher education institutions (Rosilawati & Abidin, 2025; Zahro et al., 2024). This situation indicates that although STEM is recognised as a relevant approach for enhancing 21st-century skills, its implementation in Indonesia still requires strengthening, particularly in higher education focused on developing students’ research skills. In addition, although STEM has been implemented in several institutions, there has not been strong integration with the RSD framework, which focuses explicitly on developing research skills systematically.

While STEM education is widely studied, there remains a significant gap in the literature regarding how its integration with the RSD framework impacts higher education students. This is particularly true for science education programs, where empirical evidence is still scarce. Most existing studies still focus on the general benefits of STEM without specifically examining its role in systematically developing students' research skills (Mataniari et al., 2020). Accordingly, this study examines whether a STEM-integrated RSD model is more effective than project-based learning at strengthening students' research skills. The novelty of this study lies in the integration of an interdisciplinary problem-solving approach within STEM with the structured stages of research skill development within the RSD framework. This integration enables a more systematic analysis of the development of students' research competencies, including problem formulation, data collection, analysis, and interpretation. The findings of this research are anticipated to offer a significant empirical contribution to the design of innovative, research-driven instructional models in higher education. Specifically, they aim to bolster students' readiness to navigate increasingly rigorous academic and professional expectations. This study offers empirical insights into how integrating STEM with the RSD framework enhances research skills in higher education. Specifically, it seeks to determine the effectiveness of this integrated approach in science education programs and compare its results directly against the performance of students engaged in project-based learning.

2. METHOD

Adopting a quasi-experimental approach, this research employed a pretest–posttest control-group design (Shadish & Luellen, 2012) to compare the efficacy of two instructional models. The experimental cohort was taught using a STEM-based science model integrated with the RSD framework, while the control group engaged in project-based learning. The study focused on third-semester science education students at an Indonesian university, comprising 120 participants partitioned into four experimental and four control subgroups. Purposive sampling was applied to select subjects based on their semester level and curriculum consistency. With the learning model serving as the independent variable and research skills as the dependent variable, internal validity was maintained by standardizing the instructional materials, session length, and the presiding lecturer. The research instrument consisted of a research skills test based on the interrupted case method (Herreid, 2005), designed in accordance with the RSD framework. This instrument covered six aspects of research skills, namely: (1) identifying and formulating problems, (2) determining variables, hypotheses, materials, and methods, (3) assessing data accuracy and research limitations, (4) devising procedures and organising data, (5) analysing and interpreting data, and (6) compiling reports and relating results to real-world contexts. Each aspect is assessed using a rubric on a 1–4 scale (1 = very low, 4 = very high) to describe the level of research skills progressively.

The research instrument underwent rigorous testing to ensure both validity and reliability. Validity was established through expert appraisal, and reliability was confirmed using Cronbach's Alpha, yielding $\alpha = 0.87$, indicating a high degree of internal consistency. The instrument was administered as a pretest and posttest to measure the development of research skills before and after the intervention. Data collection was carried out by administering the pretest prior to the lesson and the posttest following the intervention. The experimental group participated in STEM-integrated project-based learning guided by the RSD framework, whilst the control group participated in project-based learning. The statistical treatment of the data involved both descriptive and inferential analyses. To ensure the validity of the parametric tests, the assumptions of normality and homogeneity of variance were first assessed using the Kolmogorov–Smirnov and Levene's tests, respectively. Once these prerequisites were satisfied, an independent t-test was conducted to examine the disparity in posttest scores between the two groups. This analysis served to evaluate the comparative effectiveness of the RSD-integrated STEM approach against the project-based learning model.

3. RESULTS AND DISCUSSION

The results derived from the pretest and posttest analysis illustrate the shifts in research skills for both the experimental and control cohorts. A detailed comparison of these scores is presented in Table 1, and the visual representation of these trends is shown in Figure 1.

Table 1. Pretest And Posttest Comparison

Group	Pretest Avg	Posttest Avg	Improvement
Experiment 1	60	80	20
Experiment 2	65	85	20
Experiment 3	58	82	24
Experiment 4	62	87	25
Control 1	55	65	10
Control 2	60	70	10
Control 3	57	67	10
Control 4	59	69	10

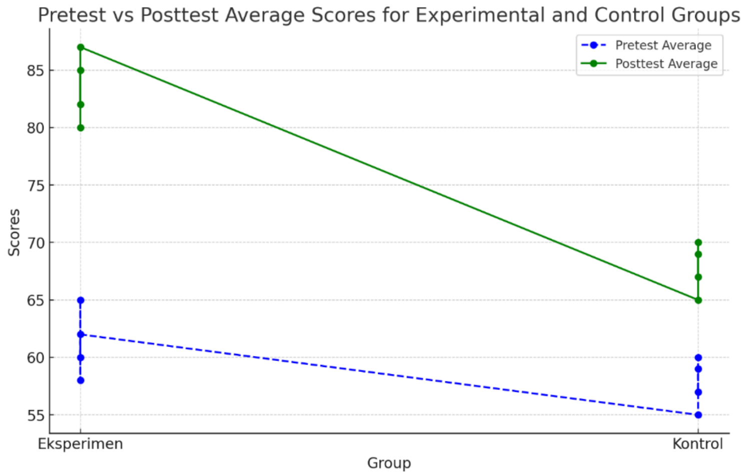

Figure 1. Comparison of pretest and posttest for experimental and control classes

The research findings reveal a pronounced disparity in the advancement of research competencies between the two cohorts. Specifically, the experimental group, using the STEM model integrated with the RSD framework, exhibited a markedly greater improvement in skills than the control group engaged in project-based learning. This difference indicates that a learning approach integrating contextual problem-solving with structured research stages is capable of having a more effective impact on the development of students' research skills. Conversely, the improvement in the control group tended to be more limited, suggesting that project-based learning does not yet fully support the in-depth development of research skills. These findings align with previous research stating that STEM-based and project-based learning can enhance students' higher-order thinking skills, active engagement, and analytical abilities (Hidayat et al., 2024; Juškevičienė et al., 2021; Malik & Zhu, 2023). Furthermore, the integration of the RSD framework provides a systematic structure at every stage of the research, enabling students to develop analytical, evaluative, and reflective skills more independently (Mataniari et al., 2020). Thus, the greater improvement in research skills observed in the experimental group can be interpreted as the result of students' engagement in authentic and structured learning experiences, which simultaneously develop their critical thinking abilities and scientific skills. This experience enables students to hone their research skills in a practical and applied manner, thereby yielding a significant improvement in their skills (Nilson, 2016).

Combining STEM methodologies with the RSD framework facilitates a more systematic and contextual evolution of research competencies. While the STEM component immerses students in interdisciplinary, real-world challenges, the RSD framework provides a scaffolded progression from initial problem formulation to final communication of results. This synergy ensures that students move beyond mere active engagement and achieve holistic mastery of the scientific inquiry process. Research indicates that STEM-based learning can enhance critical and analytical thinking skills through direct engagement in authentic tasks (Margot & Kettler, 2019; Takeuchi et al., 2020), whilst the RSD framework is effective in guiding students to develop research skills progressively and independently (Willison & Buisman-Pijlman, 2016). Furthermore, the integration of the two has been shown to strengthen students' ability to design research, analyse data, and draw evidence-based conclusions, thereby comprehensively improving the quality of their research skills (Guo et al., 2020; Anwar et al., 2022). Conversely, the control group, which used project-based learning (PjBL), also demonstrated an improvement in research skills; however, this improvement was relatively smaller than that of the experimental group. This suggests that whilst PjBL is capable of enhancing student engagement and problem-solving skills, this approach does not yet fully provide an explicit structure at every stage of the research process (Chen & Yang, 2019; Condliffe et al., 2017). In contrast, the experimental cohort following the STEM-RSD integrated approach showed consistent gains, proving that a more focused methodology is highly effective for advancing student research skills.

Theoretically, this difference can be explained by the presence of explicit stages within the RSD framework. Each stage, from problem formulation, method design, data analysis, to communication of results, is systematically facilitated, thereby helping students understand the research process holistically and progressively. This approach differs from PjBL, which tends to emphasise the final project product without always facilitating in-depth exploration at each stage of the research. Research indicates that structured, inquiry-based learning has a stronger impact on the development of scientific skills compared to approaches based solely on activities (Lazonder & Harmsen, 2016; Pedaste et al., 2015). Consequently, this research's findings suggest that the synergy between STEM and the RSD framework provides a distinct advantage over PjBL in refining students' research competencies. These results substantiate the premise that successful research skill acquisition depends not merely on project participation but on a pedagogical structure that provides explicit guidance through every phase of the investigative process. Furthermore, the integration of STEM also strengthens the link between concepts and applications, thereby promoting the development of higher-order thinking skills in a more comprehensive manner (Bybee, 2013; Kelley & Knowles, 2016). The t-test results are shown in Table 2.

Table 2. T-test results

Comparison	t-Statistic	p-Value
Experiment Vs Control	8.25	0.00017

Comparative analysis through an independent t-test revealed a robust statistical difference ($t = 8.25$; $p < 0.001$). These results provide substantial evidence that the experimental cohort, utilizing the integrated STEM-RSD framework, outperformed the control group. This confirms that the proposed model is significantly more effective in cultivating student research competencies than traditional project-based learning. The findings indicate that the STEM-based instructional model, integrated with the RSD framework, outperforms the control group in enhancing student research competencies. The experimental cohort exhibited a substantial advancement in proficiency, as reflected by the marked disparity between pretest and posttest evaluations. This growth is statistically validated by a t-statistic of 8.25 (p = 0.00017). Conversely, the control group, using project-based learning, showed only modest gains that did not reach statistical significance. The results of this study reveal that the integration of STEM with the RSD framework leads to a more pronounced advancement in research competencies. This is particularly evident in students' refined capacity for problem identification, experimental design, and systematic data interpretation. Such outcomes align with earlier literature suggesting that STEM and project-centric models foster critical thinking and active student participation (Malik & Zhu, 2023; Rosales et al., 2020). However, the inclusion of the RSD framework uniquely provides a scaffolded structure, ensuring that students move beyond mere practical engagement to achieve systematic mastery of the investigative process.

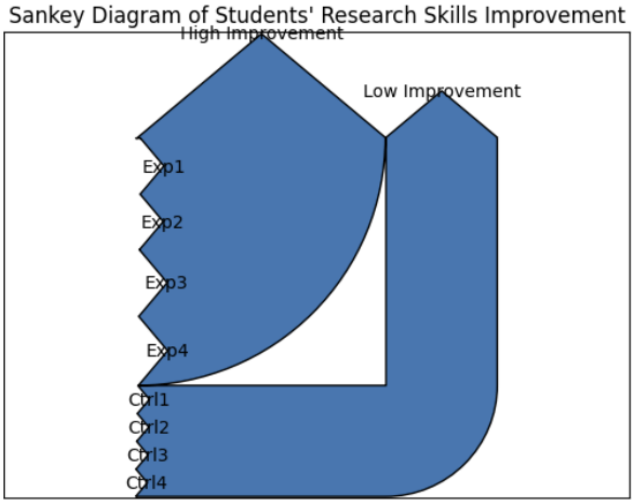

Figure 2. Diagram of changes in students' research skills

Interpretatively, this improvement in research skills can be explained by the integration of a problem-solving-based STEM approach with the structured RSD framework. This approach encourages students to learn actively, independently, and reflectively through authentic research experiences, thereby enabling them to develop analytical and scientific skills more comprehensively than through project-based learning. The results of changes in research skills during the learning process are shown in Figure 2. qThe Sankey graph above shows the flow of changes in research skills scores from the pretest to the posttest in the experimental and control groups. This diagram illustrates how the flow of scores from the pretest in both groups transitions to the posttest scores, which provides a visual representation of the improvement in students' research skills after the learning was carried out. In the experimental group, significant improvement was seen, with a transition from pretest scores of around 60 and 65 to a higher posttest score of 85. The strong flow from pretest to posttest in this group shows the significant impact of the STEM-based learning model with the RSD framework on skills researching students. In contrast, in the control group, although there was an increase from a pretest score of around 55 to a posttest of 70, the flow was more moderate and not as vigorous as the experimental group. This illustrates that the project-based learning model does not have as significant an impact as the STEM method in improving students' research skills. This analysis strengthens research findings that applying a STEM-based learning model with an RSD framework provides better results than conventional methods (Hidayat et al., 2024). The data flow in this diagram helps clarify how the experimental group experienced more significant improvements in research skills than the control group.

Previous research also shows that STEM-based learning models positively impact student skill development. According to a study by Bybee (Bybee, 2010), STEM-based learning effectively encourages students' problem-solving abilities and creativity. Another study by Becker et al. (2017) stated that integrating STEM into higher education can improve critical thinking and collaboration skills. The results of this research are in line with previous findings, but with the addition that the application of the RSD framework in STEM-based learning can accelerate the development of students' research skills, which has not been widely explored in previous research. This argument is strengthened by empirical evidence that students involved in this method experience faster development in their understanding of the scientific process and ability to handle research. The novelty of this research lies in the integration between the STEM learning model and the RSD framework. Previous research only focuses on the benefits of applying STEM in developing critical thinking or problem-solving skills. However, only some have explored how the RSD framework can be used to develop students' research skills specifically. By using the RSD framework, students are not only taught to think critically but are also given structural guidance in each stage of research. This is an added value that makes learning more effective in developing essential research skills. However, it's important to note that integrating the RSD framework in STEM-based learning may pose challenges such as the need for additional training for educators and the potential for increased workload for students. The RSD structure also allows students to adapt to higher research standards, providing them with sustainable skills that can be used in a variety of academic and professional contexts.

From the research results, students in the experimental group could move from a lower level of research skills (Level 1-2) to a higher level (Level 3-4). This shows that a student-centered and project-based learning approach allows them to be more deeply involved in the research process. They learn theory and apply this knowledge through directed research activities. In contrast to project-based learning applied in the control group, the STEM-based learning model integrated with the RSD framework enabled students to become more independent, systematic, and innovative in conducting research activities. This approach engaged students in every stage of the research process, allowing them to develop more complex and competency-based research skills, rather than merely completing project tasks. In addition, students who learn through the STEM model with RSD gain direct experience in research relevant to the real world. Using the RSD framework facilitates students not only learning how to research but also how to apply these skills in a broader context. This provides them with solid provisions to face the challenges of a world of work that increasingly prioritizes data-based and analytical skills. Thus, this model helps students in an academic context and prepares them to become competent professionals in the future. These skills also encourage students to be better prepared to deal with complex workplace and academic problems where a research-based approach is highly valued.

The significant differences between the experimental and control groups indicate that the RSD-based approach more effectively empowers students to take an active and structured role in the learning process. Although students in the control group, who were taught using PjBL, were also actively involved in completing project tasks, their engagement did not consistently encompass all stages of the research process. In contrast, students in the experimental group were systematically guided through the entire research cycle, from problem formulation to reporting results. This structured involvement enabled students to develop a deeper understanding of the scientific process, thereby accelerating the development of their research skills. These findings suggest that STEM-based learning integrated with the RSD framework provides added value beyond PjBL by offering explicit guidance at each stage of research. As a result, students are not only engaged in project activities but also develop more comprehensive research competencies, including critical analysis, evaluation, and scientific communication. This study confirms that the integration of STEM and RSD is a more effective approach for enhancing students' research skills compared to project-based learning alone. Furthermore, this approach contributes to the development of innovative, research-oriented learning models in higher education, particularly in strengthening students' readiness for academic and professional demands.

4. CONCLUSION

This study concludes that the STEM-RSD integrated model outperforms project-based learning in enhancing research skills. Statistical evidence ($t = 8.25$, $p < 0.05$) supports this, showing substantial gains in the experimental group compared to the control group. The synergy between STEM's contextual problem-solving and RSD's systematic structure proved highly effective in developing these competencies. These findings suggest that lecturers and curriculum developers should consider integrating these frameworks to strengthen students' academic readiness and cognitive abilities. However, this study has limitations, including being restricted to a single study programme with a specific sample size and a relatively short intervention duration. Therefore, future research is recommended to involve a broader, cross-institutional sample, a longer learning duration, and to examine its impact on other aspects such as students' collaboration skills and scientific literacy.

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