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Research Article

INTEGRATING STEM AND PROJECT-BASED DIGITAL WORKSHEETS TO FOSTER 21ST-CENTURY STUDENT CHARACTERS

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Abstract
This study investigates the effectiveness of STEM–Project-Based Learning (PjBL) integrated E-Student Worksheets in cultivating character development specifically curiosity and creative thinking among biology education students. Using a quasi-experimental post-test-only control group design, the research involved 50 participants equally divided into experimental and control groups. The experimental group engaged with STEM–PjBL-based E-Worksheets, while the control group used conventional worksheets. Statistical analyses, including tests of normality, homogeneity, and independent t-tests, revealed significant differences between the two groups. Students in the experimental class achieved markedly higher levels of curiosity ($M = 83.01$; $p = 0.001$) and creative thinking ($M = 79.39$; $p = 0.003$) than their counterparts, demonstrating that the integration of STEM and PjBL within digital worksheets not only increases engagement but also fosters deeper character formation by strengthening inquisitiveness, originality, and problem-solving abilities. The study provides evidence that technology-enhanced project-based learning environments can function as catalytic spaces for nurturing essential 21st-century competencies. The novelty of this research lies in its synthesis of STEM, PjBL, and character education within a single digital learning device an integration rarely explored in higher education. By embedding character attributes directly into project workflows, the E-Worksheets move beyond content delivery toward the cultivation of intellectual dispositions. This study contributes a practical framework for designing character-oriented digital learning tools, offering implications for lecturers, curriculum developers, and instructional technologists seeking to promote holistic student development through innovative, technology-supported pedagogical models.

Keywords: Character Education, E-Worksheet, PjBL, STEM

INTRODUCTION

The rapid digital transformation of the 21st century demands that students develop not only academic competence but also essential character attributes such as curiosity and creative thinking. STEM education and Project-Based Learning (PjBL) have been widely acknowledged for their potential to improve higher-order thinking skills, including critical and creative thinking (Kaur & Sharma, 2018; Nabung et al., 2022; Kiraga, 2023; Ismail et al., 2025). Within this framework, the STEM approach encompassing science, technology, engineering, and mathematics plays a pivotal role in equipping the younger generation to meet global challenges. STEM-based learning strengthens students' mastery of scientific and technological concepts and simultaneously fosters problem-solving, innovation, and creative capacities needed in an era of rapid socio-technological change (Syutaridho et al., 2023; Khan et al., 2024; Sarnoko et al., 2024; Laksono et al., 2025). As a result, STEM learning is essential for preparing future citizens who are innovative, adaptive, and capable of navigating global complexities.

Project-Based Learning (PjBL) complements STEM by providing authentic, real-world contexts that allow students to apply knowledge rather than merely absorb abstract concepts. Through planning, implementing, and evaluating complex projects, PjBL supports deep learning, strengthens critical and analytical thinking, and cultivates students' social and collaborative skills important foundations for real-life problem-solving (Almulla, 2020; Rahmania, 2021; Biazus & Mahtari, 2022; Mardiana & Ningsih, 2023; Budiarti et al., 2024; Kurniawan et al., 2025). These characteristics make PjBL highly relevant for character development, particularly in shaping attributes such as responsibility, independence, communication, and adaptive leadership skills essential for success beyond the classroom.

The introduction of Electronic Student Worksheets further enhances the implementation of STEM-PjBL by taking advantage of digital technology to support interactive, multimedia-rich learning. Digital worksheets enable students to engage with STEM concepts through videos, simulations, embedded assessments, and adaptive scaffolding, allowing more dynamic and personalized learning experiences (Budiarti et al., 2023; Yusnidar et al., 2023; Zahirah et al., 2024). By integrating text, visuals, and interactivity, E-Student Worksheets can strengthen not only cognitive mastery but also character-related attributes by encouraging independent inquiry, active exploration, and sustained engagement with learning tasks.

Despite these developments, traditional curricula still struggle to integrate character education effectively alongside academic learning. Overemphasis on cognitive outcomes often renders learning static, limiting opportunities for students to enhance curiosity, creativity, and real-world problem-solving (Puad & Ashton, 2023; Suryanto et al., 2023; Obaje, 2024). STEM instruction also faces difficulty in aligning academic content with character formation, even though STEM learning environments hold strong potential to foster curiosity and creative thinking (Beier et al., 2019; Gao et al., 2020; Zahirah et al., 2024). Therefore, there is a pressing need for learning designs that intentionally merge academic competencies with character development through integrated, project-based, and technology-enhanced approaches.

Previous studies confirm that PjBL can significantly enhance character traits such as teamwork, leadership, responsibility, and decision-making (Yanti et al., 2023; Aprida & Mayarni, 2023). Research also shows that E-Student Worksheets increase student engagement and strengthen collaborative and independent learning. Further research supports that STEM-based digital worksheets used in PjBL can create interactive environments that promote hands-on experiences and improve decision-making, communication, and thinking skills (Wahyuni et al., 2021; Sary et al., 2023; Anggraini & Asante, 2024; Rahmayani & Atmazaki, 2025).

However, existing research predominantly examines STEM, PjBL, and E-Student Worksheets as separate interventions, focusing mostly on academic outcomes such as achievement, scientific literacy, or cognitive skills. Very few studies explore their combined implementation, particularly regarding how STEM–PjBL-based E-Worksheets influence non-cognitive character traits like curiosity and creative thinking. Additionally, studies that integrate digital worksheets within STEM-PjBL rarely measure curiosity as a central outcome, leaving this character dimension understudied. Even more critically, research evaluating this integration in higher education remains limited, despite the increasing need for character formation among university students who are preparing to enter professional fields.

Thus, the primary research gap lies in the limited empirical evidence on how integrated STEM-PjBL E-Worksheets contribute simultaneously to cognitive and character development, especially curiosity and creative thinking. Previous studies have not yet provided comprehensive analyses of how these three components STEM, PjBL, and digital worksheets function collectively as a unified pedagogical model for character formation. This gap indicates a need for more systematic and targeted investigations into the character-oriented impact of technologically enriched project-based STEM learning. To address this gap, the present study aims to evaluate the effectiveness of STEM-PjBL-based

E-Student Worksheets in fostering students' curiosity and creative thinking two core 21st-century character traits essential for innovation and lifelong learning. By focusing on character outcomes rather than merely cognitive achievement, this study seeks to offer new insights and empirical evidence regarding the role of integrated digital project-based STEM learning in shaping well-rounded, future-ready individuals.

RESEARCH METHOD

This study was a quasi-experimental study. This quasi-experimental study aims to evaluate the effectiveness of a particular intervention without using a separate control group (Bärnighausen et al., 2017; Reeves et al., 2017; Miller et al., 2020). The method used by the researcher was to observe the changes that occur in the group that received the treatment, while considering other variables that may influence the results (Baier et al., 2020; Hill et al., 2021; Chesnaye et al., 2022). Although this approach may not completely control all external variables that may influence the results of the study, this approach can offer a deeper understanding of causal relationships in a more realistic context. The purpose of this study was to evaluate the efficacy of STEM-based PjBL Student Worksheet designed to support character development. The method used in this study was Post-test Only Control Group Design.

In trials, a post-test-only control group design is used to compare the effects of therapy in two groups: an experimental group, which receives the treatment, and a control group, which does not (Ghahnaviyeh et al., 2020; Keshavarz et al., 2021; Zahedian et al., 2021). In this approach, no pre-test measurements were taken before the treatment is administered; instead, measurements are taken after the treatment has been completed. This reduces the possibility of bias from the first measurement and allows researchers to evaluate the effects of the treatment more clearly.

Table 1. Post-test Only Control Research Design

Class	Treatment	Post-test
Experimental	X	T2
Control	(-)	T2

Notes:
X : Learning using PjBL-based E-Student Worksheet.
(-) : Learning using commonly used Student Worksheet.
T2 : Final test given at the end of the class.

The population consisted of students from the Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Jambi. The sample included 50 students, divided into two groups: 25 students from Class Regular B (experimental group) and 25 students from Class Regular A (control group). The sampling technique used was purposive sampling, with the criteria that participants were actively enrolled in the 2022 cohort and had similar academic backgrounds.

The instruments used in this study consisted of several components to support data collection and analysis. The primary instrument was the E-Student Worksheet integrated with STEM-PjBL, which was implemented in the experimental group, while the control group used conventional worksheets. To measure character development, character assessment instruments were employed based on two main indicators, namely curiosity and creative thinking. Curiosity was assessed through indicators such as the ability to ask questions, explore new ideas, and actively seek information, while creative thinking was measured through indicators of originality, fluency, flexibility, and elaboration. In addition, validation and practicality sheets were used to evaluate the quality of the worksheet, where experts assessed its content, construct, and media validity, and teachers as well as students provided feedback on its practicality. Finally, a post-test was administered to both groups to measure curiosity and creative thinking, using a rubric adapted from Pasani et al. (2021).

Table 2. Research Instrument Grid

Variable	Indicator	Data Source	Instrument Type
Curiosity	(1) Asking questions, (2) Actively exploring, (3) Seeking information	Student	Post-test rubric
Creative Thinking	(1) Originality, (2) Fluency, (3) Flexibility, (4) Elaboration	Student	Post-test rubric
Practicality	Ease of use, clarity, usefulness	Teacher/Student	Practicality sheet
Validity	Content, construct, and media validity	Expert	Validation sheet

The data collection in this study was carried out through several stages. First, the research instruments were validated by experts to ensure their content, construct, and media validity. After validation, the treatment was implemented in both groups, where the experimental group was taught using STEM-PjBL-based E-Student Worksheets, while the control group used conventional worksheets. At the end of the learning process, a post-test was administered to both groups to measure students' curiosity and creative thinking. Finally, student scores, teacher responses, and worksheet validation results were collected as the primary data for further analysis.

Data analysis techniques were carried out to evaluate the effectiveness of the utilization of E-Student Worksheet based on STEM-based PjBL using student post-test scores. Post-test results were analyzed using the formula.

$$Results = \frac{Total\ Score}{Maximum\ Score} x\ 100\% \ldots (1)$$

The results of student answers were calculated based on student completion and the class average obtained from the Curiosity and Creative Thinking Characters. The Curiosity and Creative Thinking indicators used in this study were in accordance with modifications (Riana & Nurhayati, 2021; Rahayuningsih et al., 2023). The achievement of the Curiosity Character was categorized into the Curiosity criteria. The percentage criteria for the Curiosity Character are as follows table 3.

Table 3. Curiosity Character Percentage Criteria

Percentage (%)	Criteria
81 – 100	Very Curious
61 – 80	Curious
41 – 60	Only Curious
21 – 40	Lack of Curiosity
0 – 20	Not Curiosity

Percentage criteria of creative thinking skill is shown table 4.

Table 4. Percentage Criteria of Creative Thinking

Percentage (%)	Criteria
81 – 100	Very Creative
61 – 80	Creative
41 – 60	Quite Creative
21 – 40	Lack of Creative Thinking
0 – 20	Not Thinking Creatively

A statistical method called the normality test is used to determine whether a dataset has a normal distribution, also known as a Gaussian distribution. Before conducting further analysis, it is important to ensure that the data meets the assumption of a normal distribution, which is one of the basic assumptions in many statistical analyses. There are several ways to perform this test, such as the Lilliefors Test, the Shapiro-Wilk Test, and the Kolmogorov-Smirnov Test. Researchers can use parametric analysis methods if the test results indicate that the data are regularly distributed; however, if the data are not regularly distributed, non-parametric analysis may be more appropriate (Khatun, 2021; Yang & Berdine, 2021; DemiR, 2022).

A statistical technique called the homogeneity test is used to determine whether the variances of two or more data sets are equal. In many statistical procedures, including regression and analysis of variance (ANOVA), homogeneity of variance is a crucial assumption because its violation can affect data analysis and interpretation (Molina-Gómez et al., 2021; Onifade & Olanrewaju, 2020; Yi et al., 2022). The standard for evaluating hypotheses is that H_0 is accepted and H_1 is rejected if the significance value is greater than 0.05. H_0 is rejected and H_1 is accepted when the significance value is less than 0.05. A t-test is performed after testing for normality and homogeneity. Data are considered normal if the significance value is higher than 0.05, and homogeneous if the significance value is higher than 0.05. A statistical method for comparing the means of two groups and determining whether there is a significant difference between them is the T-test. This test often used in research to examine data with homogeneous variance and normal distribution. The null hypothesis (H_0), which states that there is no significant difference between the two groups, and the alternative hypothesis (H_1), which states the opposite, are first formulated in the T-test. To assess the significance of the results, the significance level (α) is often set at 0.05 before the test. The T-value is then calculated based on the type of independent or paired T-test and compared with the critical value of the t-distribution table. H_0 is rejected, indicating a substantial difference, if the estimated T-value is greater than the critical value (or the p-value is less than α); on the other hand, H0 cannot be rejected if the T-value is smaller (or the p-value is greater). Next, the T-test results are evaluated within the research framework, accompanied by a discussion of the implications of the findings and how they relate to current theory or practice (Ching-Hong Li et al., 2021; Fiandini et al., 2023).

RESULTS AND DISCUSSION

Character formation data Curiosity and Creative Thinking were obtained after the treatment was given. Assessment data for students' Curiosity and Creative Thinking Characters are presented in the Table 5.

Table 5. Assessment Result of Students’ Curiosity and Creative Thinking.

Character	Class	N	Post-test Mean
Curiosity	Experimental	25	83.01
	Control	25	64.96
Creative Thinking	Experimental	25	79.39
	Control	25	60.94

The table shows that the average levels of originality and curiosity in the experimental and control groups differed significantly. The experimental group, which used PjBL and STEM-based E-Student Worksheets, had higher averages for both traits. The curiosity score was only 64.96 for the control group and 83.01 for the experimental group. Similarly, the average creativity score for the control group was only 60.94, while the experimental group's score was 79.39.

As a prerequisite for data analysis, normality and homogeneity tests were conducted before proceeding to the hypothesis testing stage. Homogeneity and normality tests are prerequisites that must be met. The researcher conducted the normality test using the Kolmogorov-Smirnov test. The findings of the post-test normality test were used for critical testing.

Table 6. Normality Test of Curiosity and Creative Thinking Value in the Post-test of Control and Experimental Class

Class	Character	Significant Value	Notes
Experimental	Curiosity	0.212	Normal
Control		0.698	Normal
Experimental	Creative Thinking	0.332	Normal
Control		0.891	Normal

The accompanying table clearly shows that the Curiosity and Creative Thinking traits are normally distributed across all experimental and control groups. Curiosity has a significance value of 0.212 in the experimental group and 0.698 in the control group, while Creative Thinking has a significance value of 0.332 in the experimental group and 0.891 in the control group. The data for each group meet the premise of normality because all significance values are higher than 0.05. The data are regularly distributed, as evidenced by the fact that all originality and curiosity scores in the control group have experimental significance values above 0.05. Data homogeneity was then assessed using Levene's test. The results of the post-test homogeneity test for Curiosity and Creative Thinking scores in the experimental and control groups are shown in the Table 7.

Table 7. Homogeneity Test of Curiosity and Creative Thinking Value in the Post-test of Control and Experimental Class

Character	Significant Value	Notes
Curiosity	0.231	Homogeneous
Creative Thinking	0.198	Homogeneous

Based on the table above, it can be concluded that the Curiosity and Creative Thinking traits in this study demonstrate homogeneity. The significance value for Curiosity is 0.231 and for Creative Thinking is 0.198, both greater than 0.05. This indicates that the data from both traits have the same variance across the tested groups, thus meeting the assumption of homogeneity.

The test results showed that the originality and curiosity data have a significance level >0.05, indicating that all data are homogeneous. The Independent Samples T-Test is used to evaluate hypotheses when the data are homogeneous and normal. The following table displays the results of the hypothesis test for critical and creative thinking skills in the experimental and control groups.

Table 8. T-Test Result for the Character of Curiosity and Creative Thinking.

Character	Class	Mean	Value	Notes
Curiosity	Experimental	83.01	0.001	H_1 is accepted
	Control	64.96		
Creative Thinking	Experimental	79.39	0.003	H_1 is accepted
	Control	60.94		

The results of the post-test analysis demonstrate that the experimental group using the STEM-PjBL-based E-Student Worksheet achieved significantly higher scores in both curiosity and creative thinking compared to the control group. Specifically, the mean score of curiosity in the experimental group was 83.01 ($p = 0.001$), while the control group obtained 64.96. Likewise, the mean score of creative thinking in the experimental group was 79.39 ($p = 0.003$), compared to 60.94 in the control group. These results answer the research question by confirming that the integration of STEM and PjBL into digital worksheets is effective in enhancing students' character development, particularly in curiosity and creative thinking. The statistical analyses, including normality and homogeneity tests followed by independent samples t-tests, confirmed the validity and reliability of these findings.

The findings of this study indicate that the integration of STEM and Project-Based Learning (PjBL) into E-Student Worksheets functions not only as a digital learning aid but also as a transformative medium for character formation. Students who engaged in authentic, inquiry-driven, and interdisciplinary projects demonstrated significantly higher curiosity and creative thinking, suggesting that the worksheets effectively bridge theoretical concepts with real-world applications. This aligns with earlier studies showing that STEM and PjBL enhance critical and creative thinking, engagement, and problem-solving (Gross et al., 2020; Silvia & Christensen, 2020; Wagstaff et al., 2021; Gould et al., 2023). By embedding exploration, hands-on investigation, and interdisciplinary reasoning, the digital worksheets created learning situations that encouraged students to ask deeper questions, explore multiple solution pathways, and construct original ideas key indicators of strengthened curiosity and creative thinking.

The significant difference between the experimental and control groups where the experimental group scored 83.01 for Curiosity and 79.39 for Creative Thinking, compared to the control group's 64.96 and 60.94 provides empirical evidence that the STEM-PjBL E-Student Worksheet effectively enhances students' character formation. This is consistent with Septiani et al. (2020), who emphasized that PjBL fosters active learning, real-world problem-solving, and student responsibility, and with Le & Aye (2025) who highlighted PjBL's potential to strengthen character. Likewise, the STEM approach integrated into the worksheets enabled students to connect scientific knowledge, technological tools, engineering design, and mathematical reasoning thus making learning more relevant and meaningful. The combination of

STEM and PjBL structures encouraged students to think divergently and converge their ideas into workable solutions, promoting both analytical and imaginative capacities.

The PjBL syntax embedded within the worksheet played a major role in strengthening curiosity and creative thinking. Students were guided through phases of questioning, investigating, designing, creating, and reflecting activities that inherently stimulate motive-based curiosity and originality. By utilizing a validated rubric adapted from Sary et al. (2023), the assessment ensured that the observed improvements reflected genuine character development rather than temporary behavioral responses. The t-test results further confirmed the worksheet's effectiveness, supporting Wahyuni et al. (2021), who argued that learning products can be considered effective when they significantly influence learner behaviors and outcomes. Thus, the findings validate that the STEM-PjBL E-Student Worksheet is not merely a technological tool but a catalyst for developing essential 21st-century character traits.

The results also align with previous studies demonstrating the capacity of STEM-PjBL worksheets to enhance higher-order thinking skills, creativity, and responsibility. For instance, Maryani et al. (2021) reported that PjBL-STEM worksheets improved creative thinking, while Rahayuningsih et al. (2023) found that similar worksheets strengthened responsibility and independence. Sukarma et al. (2024) also confirmed that STEM-PjBL promotes creativity and analytical reasoning. However, the present study advances the literature by demonstrating that *curiosity*, a foundational yet often overlooked character trait, can be significantly enhanced through STEM-PjBL-integrated digital learning. Whereas prior research tended to focus on cognitive outcomes, this study demonstrates that technology-enhanced learning can simultaneously develop cognitive and affective domains, reinforcing the view that character education should be embedded within interdisciplinary and project-based learning environments.

The novelty of this study lies in its integrated framework that combines STEM, PjBL, and digital worksheets specifically to influence character traits curiosity and creative thinking rather than focusing solely on academic performance. Unlike earlier studies that evaluated skills such as problem-solving or scientific literacy, this research foregrounds curiosity as a measurable character construct within digital learning, operationalized through validated rubric indicators. The use of a quasi-experimental post-test-only design with controlled learning conditions also provides a distinct empirical contribution by quantifying how an integrated digital learning model can shape character development. This integrated approach offers a new lens for designing character-oriented digital learning tools.

These findings carry significant implications for educators, curriculum developers, and policymakers. Practically, the results suggest that STEM-PjBL E-Student Worksheets can be implemented as innovative digital resources to improve not only student engagement but also essential character dimensions needed in modern education. For instructors, the worksheets offer a structured yet flexible tool to promote inquiry, creativity, collaboration, and autonomy. For institutions and curriculum designers, the study provides a model for integrating character education within digital, interdisciplinary, and project-driven coursework. On a policy level, the findings support curriculum modernization through character-based digital pedagogies aligned with the competencies demanded in the 21st century, ensuring that the development of curiosity and creativity is systematically embedded into learning materials.

Despite the promising results, this study has several limitations. The sample size was limited to 50 students from a single study program, which restricts the generalizability of the outcomes to broader contexts. Additionally, the post-test-only quasi-experimental design prevents in-depth measurement of pre-existing differences between groups. The short intervention period also limits the examination of long-term character development, particularly for traits like curiosity and creative thinking, which evolve over time. Moreover, the study focused only on two character traits, excluding other important dimensions such as collaboration, responsibility, communication, and leadership. Furthermore, the use of quantitative instruments alone may not fully capture students' nuanced experiences or the depth of their engagement with the E-Worksheet.

Based on these limitations, several recommendations are proposed for future research. First, studies should involve larger and more diverse samples from multiple institutions and disciplines to improve generalizability. Second, longitudinal research is necessary to track long-term changes in curiosity and creativity. Third, mixed-method approaches that combine quantitative measures with interviews, observations, or learning analytics could provide deeper insight into how students perceive and interact with STEM-PjBL digital worksheets. Fourth, future research should expand character indicators to include collaboration, independence, responsibility, and leadership to gain a more holistic understanding of character formation. Finally, upcoming innovations may explore AI-adaptive worksheets, automated feedback systems, and context-aware project tasks to further optimize personalized and character-oriented digital learning environments.

CONCLUSION

This study concludes that integrating STEM and Project-Based Learning (PjBL) into E-Student Worksheets is highly effective in fostering students' character development, particularly in the areas of curiosity and creative thinking. The experimental group consistently achieved significantly higher scores than the control group, demonstrating stronger curiosity ($M = 83.01$; $p = 0.001$) and enhanced creative thinking ($M = 79.39$; $p = 0.003$). These results confirm that digital worksheets designed with STEM-PjBL principles function not only as effective instructional tools but also as catalysts for nurturing essential character traits needed in 21st-century learning. Beyond fulfilling the research objectives, the findings contribute to a broader conceptual model in which digital learning materials serve a dual role—supporting academic performance while simultaneously cultivating character values. This positions STEM-PjBL-based E-Student Worksheets as an innovative pedagogical framework capable of bridging cognitive, affective, and practical dimensions of learning. The implications of this research are substantial. Practically, educators can utilize STEM-PjBL-based digital worksheets to increase student engagement, stimulate curiosity, and strengthen creative thinking through contextual and meaningful learning activities. Theoretically, the study emphasizes that technology-enhanced learning should be deliberately designed to promote character formation alongside knowledge acquisition, shifting the focus toward more holistic learning experiences. These insights offer a foundation for advancing character-centered digital pedagogy within STEM education. For future development, further research is recommended to apply and refine this model across diverse subject areas, educational levels, and additional character indicators such as collaboration, leadership, perseverance, and responsibility, thereby broadening its impact and ensuring its adaptability across educational contexts.

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CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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