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Effects of integrated hybrid STEM learning on 21st-century skills and character of preservice elementary teachers

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Abstract

This study investigates the impact of hybrid learning integrated with Science, Technology, Engineering, and Mathematics (STEM) on the development of 21st-century skills and character values among prospective elementary school teachers. Employing a quantitative approach, the research utilized a quasi-experimental design with a posttest control group. The sample consisted of four classes selected through purposive and simple random sampling techniques. Data were collected using a structured questionnaire, and the analysis was conducted using multivariate analysis of variance (MANOVA). The results indicated statistically significant differences between the experimental and control groups in both 21st-century skills and character values. The findings support the effectiveness of STEM-integrated hybrid learning in enhancing critical competencies required for future educators. This model promotes not only cognitive skill development but also the cultivation of essential character traits, aligning with educational goals for preparing well-rounded teacher candidates. The study emphasizes the importance of integrating interdisciplinary approaches and digital learning environments to foster both academic and personal growth in teacher education programs.

Keywords: Character education; hybrid learning; STEM integration; teacher education; twenty-first century skills

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1. INTRODUCTION

Since Contemporary educational frameworks in the twenty-first century increasingly prioritize student-centered and cooperative learning environments designed to advance cognitive development, skill acquisition, and the cultivation of appropriate attitudes (Boholano, 2017). Proficiency in conceptual understanding, experimental techniques, analytical reasoning, critical evaluation, and a broad spectrum of additional competencies is widely recognized as fundamental to effective learning (Lawrence et al., 2019; Ben Ouahi et al., 2022; Tadesse & Gillies, 2022). Nevertheless, prevailing instructional methodologies continue to be largely dominated by teacher-centered practices, resulting in passive learner participation and minimal opportunities for the application of acquired knowledge in meaningful contexts (Emaliana, 2017; Situmorang et al., 2022).

Instruction in many settings continues to be oriented around the delivery of content, often neglecting to provide adequate opportunities for formative assessment or experiential engagement that are essential for fostering critical thinking and practical skill development (Goodman et al., 2018; Komatsu et al., 2021; Ay & Dağhan, 2023). While significant emphasis is placed on the acquisition of cognitive competencies (Aleshchanova et al., 2017; Schibli et al., 2017), comparatively limited attention is directed toward the psychomotor and affective domains (Alannasir, 2020; Supena et al., 2021; Ramírez-Montoya et al., 2022). This imbalance may be attributed to a general lack of educator awareness concerning the diverse competencies essential for twenty-first century learning (Boholano, 2017; Kaput, 2018).

Achieving optimal educational outcomes requires the adoption of pedagogical approaches that align with contemporary learning demands. Research-based collaborative inquiry models have emerged as viable frameworks to overcome these challenges and reshape perceptions of the value of experiential learning. The REORCILEA model, which integrates theoretical foundations with practical application, has shown promise in sequentially enhancing learners' critical thinking and communication abilities (López-Belmonte et al., 2021).

Pedagogical strategies grounded in research-based learning are especially effective in cultivating the competencies necessary for success in modern educational contexts (Khoiri et al., 2021). These approaches necessitate active learner involvement in the full cycle of scientific inquiry, encompassing problem formulation, hypothesis generation, empirical investigation, solution development, and dissemination of findings (Nursofah et al., 2018; Susiani et al., 2018). By incorporating elements of discovery and problem-based learning, such models offer experiential opportunities that facilitate the internalization of knowledge and its application to complex, real-life scenarios (Usmeldi et al., 2017; Wessels et al., 2021; Cheng et al., 2023). Practical tasks evolve from simple guided activities to autonomous, inquiry-driven research (Camacho et al., 2017; Suntusia et al., 2019).

Collaborative learning settings are vital for encouraging meaningful dialogue and cooperative problem-solving that mirrors real-world challenges (Pires et al., 2020). Engagement in collaborative learning strengthens group dynamics, promotes shared objectives, enhances mutual understanding, and supports the development of reasoned argumentation through coordinated efforts, thereby contributing to improved educational outcomes (Fakomogbon & Bolaji, 2017; Zhang et al., 2022). Instructional models that emphasize communication within the context of collaborative inquiry foster sustained student participation and collective reflection, thereby deepening disciplinary understanding and theoretical insight (Fu & Hwang, 2018; Sung & Hwang, 2013; Bhuttah et al., 2024).

1.1. Purpose of study

This research explores the influence of a hybrid learning approach that incorporates Science, Technology, Engineering, and Mathematics (STEM) on the cultivation of twenty-first century competencies and the internalization of character values among pre-service elementary educators.

2. METHOD AND MATERIALS

The study employed a quasi-experimental methodology as outlined by Sudarsana (2018), utilizing a posttest-only control group design to examine the research hypotheses.

2.1. Participants

The sample comprised four cohorts drawn from distinct higher education institutions: Yogyakarta PGRI University (UPY), Majenang STKIP, Sultan Agung Islamic University (Unissula), and Semarang PGRI University (UPGRIS). Participants were selected through a combination of purposive and simple random sampling techniques to ensure representativeness and methodological rigor.

2.2. Data collection tools

Data were gathered using a structured questionnaire, and hypothesis testing was conducted through Multivariate Analysis of Variance (MANOVA). Prior to the application of MANOVA, it was necessary to confirm that the dataset met key statistical assumptions. Specifically, the data had to demonstrate normal distribution and homogeneity of variance. To evaluate these assumptions, a prerequisite analysis was conducted.

2.3. Data analysis technique

Assessment of normality was performed using the Shapiro-Wilk statistical test at a significance level of 0.05, implemented via SPSS version 24.00 for Windows. To evaluate homogeneity of variance, Levene's Test of Equality of Error Variances was employed, supplemented by Box's M test to assess the equality of covariance matrices. The homogeneity assumption was tested at a significance threshold of 5% ($\alpha = 0.05$). In accordance with standard statistical criteria, if the obtained F-significance value is less than 0.05, the null hypothesis is rejected in favor of the alternative hypothesis.

3. RESULTS

Prior to conducting hypothesis testing, assumption testing was performed in the form of prerequisite analyses, which included tests for data normality and homogeneity of variance. Once all necessary data had been collected, the initial step in the analysis process involved assessing the normality of the data distribution. This step is essential to determine whether the data meet the assumptions required for the application of parametric statistical methods.

The normality assessment was conducted using the Shapiro-Wilk test, with interpretation based on both the Shapiro-Wilk statistic and the corresponding Asymptotic Significance (Asymp. Sig.) value. According to established criteria, a dataset is considered normally distributed if the significance value exceeds the threshold of $\alpha = 0.05$. Conversely, if the significance value falls below this threshold, the data are considered to deviate from normality. A summary of the results from the normality test is presented in Table 2:

Table 1

Normality test

Tests of Normality

		Shapiro-Wilk		
	Class	Statistics	df	Sig.
Character Value	UPY	.983	42	.794
	STKIP MAJENANG	.941	28	.117
	UNISULA	.963	38	.236
	UPGRIS	.966	50	.163
21st Century Skills	UPY	.972	42	.398
	STKIP MAJENANG	.944	28	.143
	UNISULA	.966	38	.288
	UPGRIS	.962	50	.113

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 1 shows that the significance value of the normality test is greater than α = 0.05. Thus, it can be concluded that the overall data in the 4 groups are normally distributed.

Testing the homogeneity of variance in this study was carried out using Levene's Test of Equality of Error Variance with the help of SPSS through the Box's M test. The complete calculation of the homogeneity test for data distribution is presented in table 2.

Table 2

Homogeneity test

Box's Test of Equality of Covariance Matrices	
Box's M	13,357
F	1,447
df1	9
df2	146294.270
Sig.	.161

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + Class

Referring to Table 2, the analysis reveals a Box's M value of 13.357 with a significance level of p = 0.161. Since this value exceeds the 0.05 threshold (p > 0.05), it can be inferred that the assumption of homogeneity of covariance matrices across groups is satisfied. Consequently, the data meet the assumption of multivariate homogeneity.

Furthermore, the prerequisite tests for data analysis confirm that the dataset satisfies the assumptions of both normality and homogeneity. Given that these statistical requirements have been fulfilled, the study proceeds to hypothesis testing to examine the effects of the treatment conditions.

Table 3

Hypothesis testing

Multivariate Tests [a]

effects		Value	F	Hypothesis df	df errors	Sig.	Partial Eta Squared
Intercepts	Pillai's Trace	.998	42202.871b -	2,000	153,000	.000	.998
	Wilks' Lambda	002	42202.871b -	2,000	153,000	.000	.998
	Hotelling's Trace	551,672	42202.871b -	2,000	153,000	.000	.998
	Roy's Largest Root	551,672	42202.871b -	2,000	153,000	.000	.998
Class	Pillai's Trace	.199	5,668	6,000	308,000	.000	099
	Wilks' Lambda	.803	5,898 [b]	6,000	306,000	.000	.104
	Hotelling's Trace	.242	6.126	6,000	304,000	.000	.108
	Roy's Largest Root	.229	11,770c -	3,000	154,000	.000	.187

a. Design: Intercept + Class

b. Exact statistics

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

As presented in Table 3, the multivariate test results indicate that the calculated F-values for Pillai's Trace (F = 5.668), Wilks' Lambda (F = 5.898), Hotelling's Trace (F = 6.126), and Roy's Largest Root (F = 11.770) are all associated with significance values of 0.000, which are below the threshold of 0.05. These

findings lead to the rejection of the null hypothesis (Ho) and the acceptance of the alternative hypothesis (Ha). This result signifies that the implementation of hybrid learning integrated with Science, Technology, Engineering, and Mathematics (STEM) exerts a statistically significant influence on the development of twenty-first-century skills and character values among prospective elementary school teachers.

4. DISCUSSION

The findings derived from data analysis utilizing the Statistical Package for the Social Sciences (SPSS) version 24.0 for Windows indicate a statistically significant outcome in the Multivariate Analysis of Variance (MANOVA) test, evidenced by a significance level of 0.000, which is below the threshold of 0.05. This result substantiates the conclusion that the variable of hybrid learning, when integrated with Science, Technology, Engineering, and Mathematics (STEM) education, exerts a measurable influence on the acquisition of twenty-first-century skills as well as on the internalization of character values among pre-service elementary school teachers. These findings are consistent with the conclusions drawn by Mu'minah (2020), who observed that the integration of STEM-based pedagogy enhances academic achievement while simultaneously cultivating the competencies required for success in the twenty-first century.

Twenty-first-century skills represent a set of essential competencies necessary for individuals to effectively confront and navigate the multifaceted challenges, dilemmas, and professional demands of contemporary life (Redhana, 2019). These skills are often encapsulated under the framework of the "4Cs," which encompasses critical thinking, creativity, communication, and collaboration (Chalkiadaki, 2018). Furthermore, Lavi et al. (2021) categorize twenty-first-century skills into four interrelated domains. The first domain, "ways of thinking," includes creativity and innovation, critical thinking, problem-solving, decision-making, and metacognitive strategies. The second domain, "ways of working," refers to effective communication, collaboration, and teamwork. The third domain, "tools for working," involves general knowledge and proficiency in information and communication technologies. The fourth domain, "living in the world," pertains to socio-cultural and ethical awareness (Cevik, 2019; Edeh et al., 2022).

The incorporation of STEM into educational practice entails the application of concepts, methodologies, and interdisciplinary frameworks intended to strengthen learners' cognitive, affective, and psychomotor capacities in response to technological advancement. This view aligns with the perspectives of Artobatama (2018), Afifah and Qomariah (2018), and Oktapiani and Hamdu (2020), who contend that STEM-based learning facilitates students' engagement in designing, developing, and employing technological tools, while simultaneously nurturing their intellectual, emotional, and practical competencies. In addition, empirical studies have demonstrated that (1) STEM-oriented pedagogical approaches significantly enhance learners' critical thinking abilities; (2) the degree of improvement varies across individual critical thinking indicators; and (3) student learning outcomes, specifically in the domain of critical thinking, are superior under STEM-based instruction compared to traditional instructional methods (Khoiriyah, 2018).

The integration of STEM into education is indispensable. STEM literacy encompasses multiple dimensions, including (a) the acquisition of knowledge, attitudes, and skills that empower individuals to solve real-world problems, interpret natural phenomena, and engage in evidence-based reasoning related to STEM topics (Heather et al., 2012); (b) comprehension of the epistemological foundations and investigative nature of STEM disciplines; (c) an awareness of how STEM contributes to the material, intellectual, and ecological dimensions of human culture; and (d) a willingness to engage meaningfully with STEM-related issues and ideas as an informed, empathetic, and reflective member of society (Bartholomew, 2017).

The application of hybrid learning models that incorporate STEM principles has been shown to enhance students' conceptual understanding, critical and creative thinking capabilities, and collaborative skills. Moreover, such integration contributes positively to the development of students' national character values and fosters

attitudes conducive to ethical conduct both within educational contexts and in daily life (Suardi, 2020). The core character values aspired to by a society in the context of nation-building include: (1) faith in a supreme divine being; (2) egalitarianism, reflected in the recognition of equal human dignity irrespective of religious belief, preferences, gender, social status, or other distinctions; (3) national unity, which reflects a cohesive identity amidst diversity; (4) consensus-building through inclusive deliberative processes; and (5) social welfare, characterized by the equitable fulfillment of human needs (Hakim & Ekapti, 2019). The process of internalizing these character values involves several developmental stages, namely the acquisition of knowledge, the cultivation of awareness, the development of compliance, the exercise of volition, and the eventual formation of character and moral conscience. Effective implementation of this process necessitates collaborative engagement from multiple stakeholders.

5. CONCLUSION

The findings of this study demonstrate that hybrid learning, when integrated with the principles of Science, Technology, Engineering, and Mathematics (STEM), exerts a statistically significant influence on the development of twenty-first-century competencies and the internalization of character values among pre-service elementary school teachers. This conclusion is substantiated by the results of the Multivariate Analysis of Variance (MANOVA) test, which yielded a significance level of 0.000, a value well below the conventional threshold of 0.05. Consequently, the null hypothesis is rejected, and the alternative hypothesis is accepted.

In light of these findings, it is recommended that educators consider adopting STEM-integrated learning approaches as a viable pedagogical model within higher education institutions. Such integration holds the potential to enhance the overall quality of education, particularly by fostering the essential twenty-first-century skills and reinforcing character development among future elementary school teachers.

Conflict of Interest: The authors declare no conflict of interest.

Ethical Approval: The study adheres to the ethical guidelines for conducting research.

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