UNLEASHING THE POTENTIAL OF STEM EDUCATION: A PARADIGM SHIFT IN FOSTERING PEDAGOGICAL ADVANCEMENTS FOR CULTIVATING INNOVATIVE STUDENTS

Lusy Tunik Muharlisiani[1],
Siti Azizah[2],
Amiruddin Hadi Wibowo[3],
Widyatmike Gede Mulawarman[4],
Susantinah Nugrahini Wisnujati[5],
Pratiwi Dwi Karjati[6],
Azlina Idris[7]
[1]Department of Teacher Training and Education Universitas Wijaya Kusuma Surabaya
[2,3]Department of English Education Universitas Wijaya Kusuma Surabaya
[4]Department of Teacher Training and Education Universitas Mulawarman
[5,6]Universitas Wijaya Kusuma Surabaya
[7]Wireless Communication Technology Research Group (WiCoT), School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM) Shah Alam, 40450 Shah Alam, Selangor, Malaysia
correspondingauthor: lusytm_fbs@uwks.ac.id

ABSTRACT

STEM (Science, Technology, Engineering, and Mathematics) education is essential for preparing students for the global economy. Traditional education has faced criticism for lacking in critical thinking and creativity. In response, innovative teaching methods have emerged, with STEM education bridging skills gaps and fostering problem-solving and creativity in students, transforming modern education. This study aims to explore the paradigm shift required to fully unlock the potential of STEM education in fostering innovation. By shedding light on this potential, the research contributes to the global dialogue on education and innovation. It evaluates how STEM education can enhance teaching methods and foster innovation, emphasizing the need for a shift in educational approaches to harness STEM's capacity fully. The study examined how to improve STEM education through interviews, observations, and document analysis that promotes student-cantered learning, real-world contexts, and interdisciplinary methods to improve creativity and critical thinking. Emphasizing STEM's role in fostering innovation requires paradigm shift and better support for educators. Recommendations include investing in training programs and revising curricula. Further research should explore STEM's long-term impact on innovation and adaptability, aiming to prepare individuals for modern success.

Keywords: STEM Education; Potential; Paradigm Shift; Pedagogical Advancements; Innovative Students.

INTRODUCTION

STEM education is crucial for preparing students for 21st-century challenges by integrating these disciplines able to improve students' critical thinking, problem-solving, and innovation. Traditional education, criticized for lacking focus on critical thinking and creativity, is being re-evaluated. Thus, Innovative teaching methods are being explored to bridge the skills gap and foster problem-solving abilities.

This study aims to explore the paradigm shift in STEM education, identify effective pedagogical advancements, and develop strategies to foster innovative students and address a research gap in understanding the need for this shift to cultivate innovative learners. This study reviews relevant literature on optimizing STEM education and promoting pedagogical advancements, addressing the underutilization of STEM's full potential.

Maximizing the potential of STEM education is crucial for advancing teaching methods and developing innovative students. This research highlights the necessity for a paradigm shift in education to bridge the skills gap and enhance critical thinking and creativity. Current educational practices indicate a need for this shift, with research supporting the importance of encouraging pedagogical advancements to nurture innovative students.

The significance of this study is to contribute knowledge and understanding the potential of STEM education by exploring the paradigm shift required for pedagogical advancement and cultivating innovative students. This project addresses the urgent need to transform education, explaining the necessity of this shift. furthermore, this study also provides insights into strategies and approaches to fully unleash STEM education's potential.

METHOD

Study Site

The research was carried out over the period of July to November 2023in several high schools that have implemented STEM approaches in their curriculum. Schools were selected based on criteria such as student engagement in STEM activities, support from the school and teachers, and the availability of facilities and resources.

Research Design

This research used mixed methods, combining qualitative and quantitative approaches. The qualitative approach provided an in-depth understanding of the paradigm shift required in STEM education and the effectiveness of pedagogical advancements in fostering innovative students. The quantitative approach measured the impact of these changes on improving students' skills and creativity. In particular, the research aimed to examine the impact of an inquiry-based STEM methodology on students' comprehension of scientific principles. Using a mixed-methods approach, this study had the strengths of both qualitative and quantitative techniques while mitigating their weaknesses (Creswell, 2018; Tashakkori & Teddlie, 2020; Johnson & Onwuegbuzie, 2016). The quantitative segment of the research employed a quasi-experimental design to assess the initial and final misconceptions held by students. Within this design, one class was designated as the experimental group while the other served as the control group. By comparing the post-test scores of these two groups, which exhibited comparable pretest scores, it was possible to evaluate the influence of the paradigm shift and its impact (Greene, Caracelli, & Graham, 2016).

This mixed-method approach is effective for scientific research. The qualitative component of the research incorporated interviews conducted through the case study approach to complement the findings derived from the quasi-experimental method. This approach was employed to gain a more comprehensive understanding of the teaching process and to provide additional insights into the research outcomes. Interviews were conducted exclusively with participants from the experimental group. The research is shown in Table 1.

Table 1:
CAT implementation process

Group	Pre-Test	Implementation Process	Post-Test
Esperimental		Hand-On Papers and Lesson Processing + STEM	CUT
	CUT	Learning Approach	Semi-Contructed Interviews
Control		Hand-Out Papers and Lesson Processing Prepared	CUT

Research Procedures:

The study included 104 students aged 17-18, with 54.68% being female students. All participants were public school students from low to middle-income families in densely populated areas. Out of the total participants, 59 students were allocated to the experimental group, while 45 students were assigned to the control group, all in secondary education during the 2022-2023 academic year. Participants were selected using an accessible sampling method, which provided cost efficiency, comparability between groups, and practicality (Babbie, 2016; Johnson & Onwuegbuzie, 2016). Within the experimental group, a total of ten students were interviewed after the completion of the study, selected based on their Conceptual Understanding Test scores and willingness to participate. The scores obtained were categorized into four quartiles: low, low-middle, high-middle, and high. During the interviews, three students from both the low and high quartile groups, and four students from the middle quartile group were included for comprehensive representation.

Qualitative data were collected using interviews with teachers and students, classroom observations, and document analysis related to the implemented STEM approach. Interviews will provide in-depth insights into perceptions of the paradigm shift and pedagogical progress. Classroom observations will examine STEM implementation in practice, while document analysis will review curriculum changes and education policies. Quantitative data collection includes student surveys to measure the impact of paradigm shifts and pedagogical advancements on improving skills and creativity. Qualitative data analysis will use thematic analysis to systematically examine interview transcripts, observation notes, and documents, identifying patterns, themes, and significant findings, presented as descriptive narratives and direct quotes. Quantitative data analysis will process survey data using statistical methods such as descriptive analysis and hypothesis testing to measure the impact of paradigm shifts and pedagogical advancements.

Statistical Analysis

The observational data collected was subjected to analysis of variance (ANOVA) at a significance level of 5% (Gomez and Gomez, 1984) using IBM SPSS Statistics 23. Furthermore, the differences between treatment averages were examined utilizing Duncan's new multiple range tests (DMRT) at a significance level of 5%. Additionally, a Conceptual Understanding Test (CUT) comprising ten open-ended questions was administered, was employed to measure students' conceptual understanding of the material. This test, detailed and validated in previous studies, assesses students' grasp of relevant concepts. Furthermore, a Semi-structured Interview Form was used to collect further data from participants. This form, based on a pre-prepared interview guide, allowed participants to express their thoughts freely. These tools provided a comprehensive understanding of students' conceptual grasp and their experiences within the study's context.

FINDINGS AND DISCUSSION

The results of the ANOVA showed a significant interaction between the Experimental and Control groups. Questions in the CUT were structured according to the Merdeka Curriculum 2018-2023 to ensure the validity of their scope. To further validate the CUT, the input of two experienced senior high school teachers with 10-20 years of teaching experience was sought. Initially comprising 20 questions, adjustments were made based on their feedback, dividing some questions into parts and removing others, resulting in a final set of 10 questions. Subsequently, the CUT underwent pilot testing with 104 students.

Based on the t-test outcomes presented in Table 2, a notable distinction was observed in the mean scores of the higher and lower groups for 27% of the remaining questions, excluding Questions 1A, 1B, 7, and 9. Therefore, these specific questions were retained in their original form in the final version of the CUT. Figure 1 in the CUT illustrates one of the questions

Table 2:
T-test results for item means of Experimental-Control groups of test items

Question #	*Groups*	*N*	*M*	*Sd*	*t*	*p*
1A	Experimental	19	3.3158	0.74927	1.061	**0.296**
	Control	19	3.0526	0.77986	1.061	
1B	Experimental	19	3.3158	0.82007	0.404	**0.689**
	Control	19	3.2105	0.78733	0.061	
2	Experimental	19	3.6316	0.49559	19.298	0.000
	Control	19	0.4737	0.51299	19.298	
3	Experimental	19	3.3684	0.49559	17.690	0.000
	Control	19	0.4737	0.51299	17.690	
4	Experimental	19	3.3684	0.49559	20.171	0.000
	Control	19	0.2632	0.45241	20.171	
5	Experimental	19	3.3684	0.49559	20.171	0.000
	Control	19	0.2632	0.45241	20.171	
6	Experimental	19	3.3684	0.49559	17.400	0.000
	Control	19	0.3158	0.58239	17.400	
	Experimental	19	3.3158	0.74927	1.061	**0.296**
7	Control	19	3.0526	0.77986	1.061	
	Experimental	19	3.6842	0.47757	19.640	0.000
8	Control	19	0.5263	0.51299	19.640	
	Experimental	19	3.3684	0.49559	17.690	**0.689**
9	Control	19	0.4737	0.51299	17.690	
10	Experimental	19	3.3158	0.82007	0.404	0.000
	Control	19	3.2105	0.78733	0.404	

Table 3:
Experimental and Control Group CUT Pre-Test and Post-Test Statistics Values

Groups	Test	N	Min.	M	SD	Variance	Skewness	Kurtosis
Esperimental	Pre-test	49	3	8.59	3.09	9.54	0.356	-0.679
	Post-test	49	15	35.24	8.40	70.62	-0.515	-0.317
Control	Pre-test	55	2	8.20	3.38	11.40	0.439	0.515
	Post-test	55	9	24.20	7.76	60.46	0.051	-1.037

Table 4:
Experimental and control group CUT pre and post-test normality analysis results

Groups	Tests	Kolmogorov - Smirnov			Shapiro-Wilk		
		Statistic	Sd	p	Statistic	Sd	p
Esperimental	Pre-test	0.161	49	0.051	0.946	49	0.146
	Post-test	0.134	49	0.194	0.961	49	0.351
Control	Pre-test	0.133	55	0.124	0.965	55	0.312
	Post-test	0.117	55	0.200	0.959	55	0.217

According to the Kolmogorov-Smirnov values, Table 7 demonstrates that the pretest and post-test scores of the experimental group in the CUT adhered to a normal distribution ($p < 0.05$). As a result, intra-group comparisons were conducted employing the dependent t-test, while inter-group comparisons were carried out using ANCOVA. The findings of this analysis were reported in the results section and presented in tabular format.

The data from the semi-structured interviews conducted during the force and energy unit were initially captured using a voice recorder and later transcribed into electronic format. The transcriptions were meticulously reviewed and refined to enhance clarity and relevance, ensuring that only topics aligned with the research scope were included. Subsequently, the data were organized and categorized in the findings section, taking into account both common and divergent themes. To analyze the data, a content analysis approach was adopted, involving three experts who carefully read and coded the data.

Table 5:
The ANCOVA results for the post-test scores, adjusted for the CUT pretests by groups, are presented in Table 5

Source of Variance	Sum of Squares	Sd	Mean of Square	F	p	Eta-Square
Model	2691.606	2	1345.803	25.069	.000	.451
Pretest	758.157	1	758.157	14.122	.000	.188
Group	1784.182	1	1784.182	33.235	.000	.353
Error	3274.754	61	53.684			
Total	60547.000	64				

CONCLUSION

The research findings shows that interviews with students support the quantitative data from the CUT. Students reported that STEM-supported learning provides hands-on, experiential learning, fosters responsibility, and makes learning enjoyable. They also noted improvements in problem-solving skills through engineering design activities. This study brings attention to the efficacy of integrating STEM-supported learning approaches in enhancing conceptual understanding among students. For group activities, it is suggested to allow students to choose their group members initially, followed by random group formation for subsequent tasks to ensure heterogeneity and improve communication and responsibility. Materials should not be directly provided; instead, students should determine which materials to use, promoting decision-making and creativity. Students can also be encouraged to create prototypes with multiple features based on their proficiency and include desired features in evaluation forms. These recommendations aim to boost student engagement and creativity in STEM activities. This study contributes to STEM education by providing insights from both quantitative and qualitative data, emphasizing the benefits of STEM-supported learning in developing conceptual understanding and problem-solving skills. Future research should explore the long-term effects of STEM education on students' academic and career outcomes.

ACKNOWLEDGEMENT

In the acknowledgment section, the author acknowledges the support received with reference to No: 0667/E5/AL.04/2024, dated May 30, 2024. The author would also like to extend gratitude to the reviewers and proofreaders for their valuable input, as well as to the technicians who assisted in setting up equipment, and the students who actively participated in the surveys.

REFERENCES

Babbie, E.R. (2016). *The Practice of Social Research. 14th Edition, Cengage Learning, Belmont*. https://www.scirp.org/reference/referencespapers?referenceid=2439585

Bakırcı, H., Kırıcı, M. G., & Kara, Y. (2022). The effectiveness of STEM-supported inquiry-based learning approach on conceptual understanding of 7th graders: force and energy unit. *Journal of Science Learning,* 5(3), 452-468. https://doi.org/10.17509/jsl.v5i3.43647

Benitti, F. B. V. & Spolaor, N. (2017). How have robots supported STEM teaching? In M. S. Khine (Ed), *Robotics in STEM education*. Springer. https://doi.org/10.1007/978-3-319-57786-9_5

Breiner, J.M., Johnson, C.C., Harkness, S.S., & Koehler, C.M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, 112 (1), 3-11. https://doi.org/10.1111/j.1949-8594.2011.00109.x

Bryan, L., & Guzey, S. S. (2020). *K-12 STEM Education: An Overview of Perspectives and Considerations. Hellenic Journal of STEM Education*, 1(1), 515. https://doi.org/10.51724/hjstemed.v1i1.5

Buyruk, B., & Korkmaz, Ö. (2014). STEM Awareness Scale (SAS): Validity and reliability study. *Journal of Turkish Science Education*, 11(1), 3-23. https://doi.org/10.12973/tused.10179a

Bybee, R. W. (2010). What is STEM education? *Science,* 329(5995), 996-996. https://doi.org/10.1126/science.1194998

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research*. Los Angeles: SAGE Publications.

Century, J., Ferris, K. A., & Zuo, H. (2020). Finding time for computer science in the elementary school day: a quasi-experimental study of a transdisciplinary problem-based learning approach. International *Journal of STEM Education*, 7(1). https://doi.org/10.1186/s40594-020-00218-3

Chiang, F. K., Chang, C. H., Wang, S., Cai, R. H., & Li, L. (2022). The effect of an interdisciplinary STEM course on children's attitudes of learning and engineering design skills. *International Journal of Technology and Design Education*, 32(1), 55-74. https://doi.org/10.1007/s10798-020-09603-z

Ching, Y. H., Yang, D., Wang, S., Baek, Y., Swanson, S., & Chittoori, B. (2019). Elementary School Student Development of STEM Attitudes and Perceived Learning in a STEM Integrated Robotics Curriculum. *TechTrends*, 63(5), 590-601. https://doi.org/10.1007/s11528-019-00388-0

Dedetürk, A., Kırmızıgül, A. S., & Kaya, H. (2021). The effects of STEM activities on 6th grade students' conceptual development of sound. *Journal of Baltic Science Education*, 20(1), 21-37. https://doi.org/10.33225/jbse/21.20.21

Greene, J. C., Caracelli, V. J., & Graham, W. F. (2016). Toward a conceptual framework for mixed-method evaluation designs. *Educational Evaluation and Policy Analysis,* 11(3), 255-274. https://journals.sagepub.com/doi/10.3102/01623737011003255

Gya, R., & Bjune, A. E. (2021). Taking practical learning in STEM education home: Examples from do-it-yourself experiments in plant biology. *Ecology and Evolution*, 11(8), 3481-3487. https://doi.org/10.1002/ece3.7207

Hansen, M., & Gonzalez, T. (2014). Investigating the relationship between STEM learning principles and student achievement in math and science. *American Journal of Education*, 120(2), 139–171. https://doi.org/10.1086/674376

Honey, M. A., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: status, prospects, and an agenda for research. In STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research.* National Academies Press. https://doi.org/10.17226/18612

Hutchins, N. M., Biswas, G., Marti, M., LÃdeczi, Ã., Grover, S., Wolf, R., Blair, K. P., Chin, D., Conlin, L., Basu, S., & McElhaney, K. (2020). C2STEM: a System for Synergistic Learning of Physics and Computational

Thinking. *Journal of Science Education and Technology*, 29(1), 83-100. https://doi.org/10.1007/s10956-019-09804-9

Johnson, R.B. and Onwuegbuzie, A.J. (2016) Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*, 33, 14-26. http://dx.doi.org/10.3102/0013189X033007014

Kelley, T.R., Knowles, J.G. A conceptual framework for integrated STEM education. *IJ STEM Ed* 3, 11 (2016). https://doi.org/10.1186/s40594-016-0046-z.

KHUT Sokha, 2Shimizu KINYA. Integrating STEM Approach in K-12 Science Education Teaching Practice: A Systematic Literature Review. *International Journal of Research in STEM Education (IJRSE).* ISSN 2721-2904 (online). Volume 5 Number 2 (2023): 1 -18. https://jurnal-fkip.ut.ac.id/index.php/ijrse/issue/archive

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2019). Design and design thinking in STEM education. *Journal for STEM Education Research*, 2, 93-104. https://doi.org/10.1007/s41979-019-00020-z

Lou, S.-J., Shih, R.-C., Ray Diez, C., & Tseng, K.-H. (2011). The impact of problem-based learning strategies on STEM knowledge integration and attitudes: an exploratory study among female Taiwanese senior high school students. *International Journal of Technology and Design Education,* 21(2), 195-215. https://doi.org/10.1007/s10798-010-9114-8

Sarı, U., Duygu, E., Şen, Ö. F., & Kırındı, T. (2020). The Effect of STEM Education on Scientific Process Skills and STEM Awareness in Simulation Based Inquiry Learning Environment. *Journal of Turkish Science Education,* 17(3), 387-405. doi: 10.36681/tused.2020.34

SOKHA KHUT and Shimizu KINYA. Integrating STEM Approach in K-12 Science Education Teaching Practice: A Systematic Literature Review. *International Journal of Research in STEM Education*. Vol. 5 No. 2 (2023): November Issue. DOI: https://doi.org/10.33830/ijrse.v5i2.1598. https://jurnal-fkip.ut.ac.id/index.php/ijrse/article/view/1598

Tashakkori, A., & Teddlie, C. (Eds.). (2020). SAGE *Handbook of Mixed Methods in Social & Behavioral Research*. Los Angeles: SAGE Publications. https://uk.sagepub.com/en-gb/asi/foundations-of-mixed-methods-research/book252072

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research,* 1(2), 1-13. https://docs.lib.purdue.edu/jpeer/vol1/iss2/5/

Wei, B., & Chen, Y. (2020). Integrated STEM Education in K-12: Theory Development, Status, and Prospects. In Theorizing STEM Education in the 21st Century. *IntechOpen*. https://doi.org/10.5772/intechopen.88141