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The Effectiveness of 6E Learning by Design™ Approach in Enhancing High School Physics Education on Students' STEM Literacy and Motivation towards STEM Fields

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Abstract

With the rapid advancement of the global economy and technology, the importance of STEM education has become increasingly prominent. However, many educational systems face challenges related to declining student interest and engagement in STEM fields. This study aims to explore the effectiveness of the 6E Learning byDeSIGN™ approach in enhancing students' STEM literacy and motivation in high school physics education, compared to traditional methods. A quasi-experimental design was employed with 100 high school students divided into an experimental group, taught using the 6E approach, and a control group, receiving traditional instruction. Pre- and post-tests assessed STEM literacy and motivation. Results indicated that the experimental group significantly outperformed the control group, with notable increases from pre- to post-test within the experimental group. The findings provide empirical support for the integration of innovative instructional strategies in STEM education, offering practical implications for educators, curriculum developers, and policymakers.

Keywords: STEM Literacy, 6E Learning byDeSIGN™, High School Physics, Motivation towards STEM Fields

Introduction

As the global economy and technology continue to develop at a rapid pace, STEM (Science, Technology, Engineering and Mathematics) education gets more and more attention. It is crucial to prepare students with the skill sets they need to be successful in the technology-driven world. Nonetheless, most educational systems are finding it difficult, since many students lose interest and engagement in fields of science, technology, engineering, and mathematics (STEM), pointing to the pressing need for invigorating methods of teaching to develop STEM literacy and enhance students' motivation (Chisom et al., 2023).

Confronted with these challenges, national policies to bridge skills gaps in technologically intensive sectors (Zhbanova, 2019) have become closely aligned with global STEM education reform. These amongst various other countries; the United States, Australia and some European countries focus on an interdisciplinary teaching approach which aims at growing creativity, critical thinking, and problem-solving (Aguilera & Ortiz-Revilla, 2021). But literacy in STEM requires more than learning science and maths concepts. It requires knowledge to be applied to real-world problems. Being able to do math is essential for success not just in academics but to meaningfully contribute to a technology-driven world (Ah-Namand & Osman, 2018). Statistics obtained from research consistently demonstrate higher levels of motivation to pursue STEM careers and to improve cognitive and affective outcomes when a person has a higher level of STEM literacy (Falloon et al., 2020).

It is motivation towards STEM fields which drives students' engagement and ultimately their career choices to be made. Motivation is shown to depend on self-efficacy, interest and the learning environment (Garriott & Nisle, 2015; Sáinz et al., 2022). Nevertheless, studies have shown that high dropout rates among STEM students may be attributed to poor levels of motivation, in that those with high levels of motivation achieve high academic performance and are more likely to pursue rewarding STEM careers (Bayanova et al., 2023). In this regard, there have been studies that discovered educational strategies that drive active learning, real-world applications, and collaboration to promote student motivation (Baran et al., 2019; Cabrera et al., 2023).

A model and method example of one such strategy, the 6E Learning byDeSIGN™ approach, is outlined — a learning process integrating the phases of Engage, Explore, Explain, Engineer, Enrich and Evaluate. This model, based on inquiry, stimulates hands-on, active learning that enhances the depths of engagement with STEM content (Barry, 2014). Results of submersion research (Maknun, 2020) indicate that the 6E Learning byDeSIGN™ approach has an impact on both cognitive and affective learning outcomes. Allowing the students to explore in practice the concepts through practical application and experimentation gives them better learning outcomes. Further studies show that this approach also considerably increases student engagement, especially in hard-to-engage subjects like high school physics. Physics is often intimidating and viewed as mathematically abstract and that's difficult to understand, but the scaffolded and structured nature of the 6E method allows students to more easily tackle these complex concepts to develop a longer-lasting understanding (Trevissoi, 2024; Yang et al., 2020).

However, while there are numerous advantages to using these tools to teach STEM, traditionally these lessons have focused on passive learning and rote memorization, and often fail to engage students. This method doesn't help to develop the critical thinking skills or problem-solving skills that are needed in the STEM fields (Dyrberg & Holmegaard, 2019). Conventional pedagogies are lacking and dynamic, student-centered instructional approaches are needed. The 6E Learning byDeSIGN™ approach addresses many of these issues, yet there is little research about its impact within high school physics specifically.(Hsiao et al., 2023).

In order to fill this gap, the current study evaluates the impact of the 6E Learning byDeSIGN™ approach on the improvement of STEM literacy as well as on the motivation of high school students in physics education. In particular, this research focuses on how the effectiveness of the 6E approach functions in terms of increased student understanding of STEM concepts and increased student motivation to work in an area related to STEM. This research question will be studied:

(1) How effective is the 6E Learning byDeSIGN™ approach in enhancing high school students' STEM literacy in physics education?

(2) How effective is the 6E Learning byDeSIGN™ approach in enhancing high school students' motivation towards STEM fields?

Based on these questions, the following hypotheses will be tested:

(H01) The 6E Learning byDeSIGN™ approach does not significantly improve high school students' STEM literacy compared to traditional methods.

(H02) The 6E approach does not significantly enhance motivation towards STEM fields compared to traditional instructional methods.

Literature Review

STEM Literacy

STEM literacy is being able to know about and use science, tools, engineering, and math to solve problems in the real world, make informed decisions, and reason and think critically and by inquiry (Falloon et al. 2020). Preparing students to navigate an increasingly technology-driven world will require STEM literacy, the ability to apply STEM knowledge to real-world contexts, but also to not just know it cognitively but to be able to synthesise an inquiry mindset to be able to engage and interrogate complex systems. If we're trying to look at improving individual flourishing and societal progress then STEM literacy becomes important because it means people can either think about what will inform future innovations and future decision-making (Aguilera & Ortiz-Revilla, 2021; Ammar et al., 2024).

Strategies such as inquiry-based learning (EBL), project-based learning (PBL), or digital tools integration that support STEM literacy practice make kids more or less, actively engaged and apply the STEM concept in practice (Shernoff et al., 2017). STEM literacy assessment needs to take on both traditional and dynamic characteristics, such as performance-based assessments that measure the student's problem-solving abilities and formative assessments that provide ongoing information about the learning process (Aguilera & Ortiz-Revilla, 2021; Marchisio et al., 2018).

The efforts in China to promote STEM literacy include integrating the STEM content across the subjects, and the culturally relevant teachings to make learning interesting (Meng et al., 2022; Qian et al., 2023). Moreover, the use of digital platforms was pointed out to develop an interactive learning environment and augment STEM literacy (Wang & Li, 2022).

Motivation towards STEM Fields

The Motivation to STEM fields is critical for keeping student engagement, academic success and interest in STEM careers. Intrinsic motivation is intrinsic motivation, that is personal interest and extrinsic motivation is that which is influenced by external factors like recognition (Ryan & Deci, 2020). The relevant indicators of motivation are self-efficacy, perceived relevance of STEM and goal orientation (Bayanova et al., 2023). According to Dotterer (2022), highly motivated students score well in academics and are persistent in their STEM education.

Strategies to increase motivation are effective with inquiry-based learning (IBL), making real-world connections, promoting a growth mindset, providing role models, and using collaborative environments (Theobald et al., 2020; Dweck, 2016; Ryan & deci, 2020). The Motivated Strategies for Learning Questionnaire (MSLQ) and STEM attitude surveys aid understanding of students' motivational profiles, and inform where targeted interventions may be useful (Pintrich et al., 1993; Woldeamanuel et al., 2019).

Cultural values, parental expectations, and recent educational reforms to promote student-centered approaches away from rote learning impelled motivation to STEM in China (Wang & Luo, 2022). The objective of this study is to assess the efficacy of the 6E Learning byDeSIGN™ approach in improving high school students' STEM literacy and motivation and to provide constructive suggestions and results for innovative pedagogical practices in the Chinese context.

6E Learning byDeSIGN™ Approach

The 6E Learning byDeSIGN™ Approach, an extension of the 5E instructional model, incorporates the phases: Explore, Engage, Explain, Engineer, Enrich, and Evaluate. Created to improve STEM education by combining engineering principles and design thinking, while promoting creativity, innovation and real-life problem solving (Burke, 2014; Yazıcı et al., 2023). A student-centred approach is required when implementing care that is active, participatory, and based on hands-on learning in a collaborative setting.

The 6E Approach has been used in high school physics education to improve conceptual understanding and students' problem-solving ability through the opportunity for students to explore and apply abstract theories in everyday contexts (Yang et al., 2020). Furthermore, in the particular "Engineer" phase, students engage in design-based learning to build models and refine hypotheses that in turn promote creativity and deepen understanding (Yazıcı et al., 2023).

In the 6E Approach, higher engagement, better critical thinking, and group learning (Salikha et al., 2021; Hsiao et al., 2023) are considered as its advantages. Yet its wide-scale use is hindered by challenges that include resource intensity, teacher training requirements, and complex assessment (Yang et al., 2020; Shernoff et al., 2017). The 6E Approach in China, which in turn has fostered STEM literacy, has faced challenges in under-resourced schools in China. Efforts to mitigate these are things like teacher training and local partnerships (Yang et al., 2020; Zhong et al., 2022).

Methods

The 6E Learning byDeSIGN™ approach was evaluated for its ability to enhance the high school students' STEM literacy and motivation toward STEM fields in physics education through a quasi-experimental design. A total of 100 students from two classes of a county-level high school in China were chosen for the study. The experimental group was assigned to one class, which received instruction through 6E Learning by DeSIGN™ and the control group received instruction via traditional teaching methods.

Sampling and Participants

100 high school students taking physics courses constituted the sample. To select two comparable classes, sufficiently large for statistical analysis, purposive sampling was used. To test the effectiveness of the learning by DeSIGN™ system, an experimental group implemented the 6E Learning byDeSIGN™ approach, while the control group continued to undertake traditional instruction. The two groups were taught the same physics curriculum in which they were taught circuits, resistivity, and energy conservation.

Data Collection and Analysis

Pretest and post-test assessments were used to collect quantitative data to see changes in STEM literacy and STEM motivation. Also, the High School Students' STEM Literacy Questionnaire (Zhang, 2021) and Motivation Scale for STEM Fields (Kızılay et al., 2019) were distributed pre- and post-intervention. The reliability and validity of both instruments were pre-tested.

Independent samples t-tests were applied to compare post-test scores between the experimental group and the control group of the collected data. Changes in each group from pre-test to post-test were analyzed by using paired samples t-tests. Furthermore, pre-test comparisons were used to ensure group equivalence before intervention. The capability to evaluate the effectiveness of the 6E Learning byDeSIGN™ approach in improving STEM literacy as well as student motivation was realized because of these statistical methods.

Results

Analysis was drawn from data gathered from 100 high school students, broken down into experimental and control groups, on the effectiveness of the 6E Learning byDeSIGN™ approach to addressing STEM literacy and motivation. Then descriptive statistics were calculated to describe the data distribution after data cleaning and preparation. Internal consistency of the survey instruments was confirmed by reliability analysis, and assumption testing confirmed suitability for parametric analysis of the data. Then inferential statistical tests (t-tests) were conducted to compare the pre and post-test results between the experimental and control groups on the effects of the 6E approach.

Descriptive Statistic

STEM Literacy Descriptive Statistics

As shown in Table 4.1, the experimental group's mean STEM literacy score increased from 175.20 (SD = 20.15) at pre-test to 195.40 (SD = 22.30) at post-test. In contrast, the control group's mean score showed a slight increase from 174.80 (SD = 19.80) to 178.00 (SD = 21.05). The increase in the experimental group's mean score suggests a positive effect of the 6E Learning byDeSIGN™ approach on students' STEM literacy.

Table 1
Descriptive Statistics for STEM Literacy Scores

Group	Test	N	Mean	Standard Deviation (SD)	Minimum	Maximum
Experimental	Pre-test	50	175.20	20.15	139	210
	Post-test	50	195.40	22.30	155	235
Control	Pre-test	50	174.80	19.80	140	209
	Post-test	50	178.00	21.05	142	212

Motivation Towards STEM Fields Descriptive Statistics

From Table 2, the experimental group's mean motivation towards STEM fields score increased from 75.30 (SD = 10.25) at pre-test to 85.50 (SD = 12.10) at post-test. The control group's mean score showed a marginal increase from 74.90 (SD = 10.05) to 77.20 (SD = 11.15). This indicates that the experimental group experienced a more substantial improvement in motivation towards STEM fields compared to the control group.

Table 2
Descriptive Statistics for Motivation towards STEM Fields Scores

Group	Test	N	Mean	Standard Deviation (SD)	Minimum	Maximum
Experimental	Pre-test	50	75.30	10.25	60	95
	Post-test	50	85.50	12.10	65	100
Control	Pre-test	50	74.90	10.05	60	95
	Post-test	50	77.20	11.15	62	97

Independent Samples T-Tests

Reliability analysis confirmed acceptable to excellent internal consistency for both the STEM Literacy and Motivation Scales, and assumption testing verified that the data met the normality and homogeneity of variance requirements, supporting the validity of subsequent t-test analyses.

STEM Literacy Pre-test Analysis

An independent samples t-test was performed to compare the pre-test STEM literacy scores between the experimental and control groups. The t-test indicated no significant difference between the experimental group (M = 175.20, SD = 20.15) and the control group (M = 174.80, SD = 19.80), $t(98) = 0.097$, $P = 0.923$. This result suggests that both groups had comparable levels of STEM literacy prior to the intervention.

Table 3
Independent Samples t-test for STEM Literacy Pre-test Scores

Group	N	Mean	SD	t	df	p-value
Experimental	50	175.20	20.15	0.097	98	0.923
Control	50	174.80	19.80			

Motivation Pre-test Analysis

An independent samples t-test was conducted for the pre-test motivation towards STEM fields scores. The analysis revealed no significant difference between the experimental group

(M = 75.30, SD = 10.25) and the control group (M = 74.90, SD = 10.05), t(98) = 0.199, p = 0.843. This indicates that the groups were similarly motivated towards STEM fields before the implementation of the instructional intervention.

Table 4
Independent Samples t-test for Motivation Towards STEM Fields Pre-test Scores

Group	N	Mean	SD	t	df	p-value
Experimental	50	75.30	10.25	0.199	98	0.843
Control	50	74.90	10.05			

STEM Literacy Post-test Analysis

The absence of significant differences in pre-test scores confirmed the initial equivalence between the experimental and control groups, ensuring that any post-test differences could be attributed to the 6E Learning byDeSIGN™ approach. An independent samples t-test showed a significant improvement in STEM literacy for the experimental group (M = 195.40, SD = 22.30) compared to the control group (M = 178.00, SD = 21.05), t(98) = 4.237, p < 0.001, with a large effect size (Cohen's d = 0.848). This result supports the rejection of Null Hypothesis 1 and confirms that the 6E Learning byDeSIGN™ approach significantly enhances STEM literacy in high school physics education compared to traditional methods (Cohen 1988).

Table 5
Independent Samples t-test for STEM Literacy Post-test Scores

Group	N	Mean	SD	t	df	p-value	Cohen's d
Experimental	50	195.40	22.30	4.237	98	<0.001	0.848
Control	50	178.00	21.05				

Motivation Post-test Analysis

An independent samples t-test for post-test motivation towards STEM fields revealed a significant difference between the experimental group (M = 85.50, SD = 12.10) and the control group (M = 77.20, SD = 11.15), t(98) = 3.861, p < 0.001, with a medium to large effect size (Cohen's d = 0.774). This result supports the rejection of Null Hypothesis 2 and demonstrates that the 6E Learning byDeSIGN™ approach significantly enhances high school students' motivation towards STEM fields compared to traditional instructional methods.

Table 6
Independent Samples t-test for Motivation Towards STEM Fields Post-test Scores

Group	N	Mean	SD	t	df	p-value	Cohen's d
Experimental	50	85.50	12.10	3.861	98	<0.001	0.774
Control	50	77.20	11.15				

Paired Samples T-Tests

Paired samples t-tests were conducted within each group to examine changes in STEM literacy and motivation towards STEM fields from pre-test to post-test. This analysis helps to understand the effectiveness of the instructional methods over time within each group.

STEM Literacy Scores in the Experimental Group

A paired samples t-test compared the experimental group's pre-test and post-test STEM literacy scores. The analysis revealed a significant increase in STEM literacy scores from pre-test to post-test, $t(49) = -10.049$, $p < 0.001$. The effect size was 1.422, indicating a very large effect.

Table 7
Paired Samples t-test for STEM Literacy Scores in the Experimental Group

Test	Mean	SD	t	df	p-value	Cohen's d
Pre-test	175.20	20.15	-10.049	49	<0.001	1.422
Post-test	195.40	22.30				

Motivation towards STEM Fields Scores in the Experimental Group

A paired samples t-test was also conducted for motivation towards STEM fields scores. The results indicated a significant increase from pre-test to post-test, $t(49) = -7.365$, $p < 0.001$. The effect size was 1.041, denoting a large effect.

Table 8
Paired Samples t-test for Motivation Towards STEM Fields Scores in the Experimental Group

Test	Mean	SD	t	df	p-value	Cohen's d
Pre-test	75.30	10.25	-7.365	49	<0.001	1.041
Post-test	85.50	12.10				

Within-Group Comparisons for the Control Group

In the control group, paired samples t-tests revealed no significant differences between pre-test and post-test scores for both STEM literacy, $t(49) = -1.404$, $p = 0.166$, and motivation towards STEM fields, $t(49) = -1.445$, $p = 0.154$. These results suggest that traditional instructional methods did not lead to notable improvements in either measure, highlighting the contrast with the experimental group's outcomes.

Table 9
Paired Samples t-test for STEM Literacy Scores in the Control Group

Test	Mean	SD	t	df	p-value	Cohen's d
Pre-test	174.80	19.80	-1.404	49	0.166	0.199
Post-test	178.00	21.05				

Table 10
Paired Samples t-test for Motivation Towards STEM Fields Scores in the Control Group

Test	Mean	SD	t	df	p-value	Cohen's d
Pre-test	74.90	10.05	-1.445	49	0.154	0.204
Post-test	77.20	11.15				

Summary of Key Findings

The findings of this study confirm that the 6E Learning byDeSIGN™ approach significantly improves high school students' STEM literacy and motivation towards STEM fields in physics education. The experimental group showed substantial gains in both measures, with significant differences observed in post-test scores compared to the control group. Independent and paired samples t-tests revealed that the experimental group outperformed the control group, and within-group improvements were noted only in the experimental group. The positive impact on students' STEM competencies and motivation highlights the potential of this innovative teaching approach for enhancing learning outcomes in STEM education.

Discussion

This study confirms that the 6E Learning byDeSIGN™ approach significantly improves high school students' STEM literacy and motivation towards STEM fields in physics education. The experimental group demonstrated substantial improvements compared to the control group, aligning with previous research on experiential and design-based learning models.

Enhancement of STEM Literacy

The result of this study is consistent with the available literature on innovative instructional methods in STEM education: 6E Learning byDeSIGN™ approach increases STEM literacy and enhances students' motivation (Bozkurt & Tan, 2021; Saritepeci & Yildiz, 2024). These results complement previous research which has found that inquiry-based learning environments enhance students' understanding of scientific concepts. The 6E approach is, therefore, a teaching method which provides a structured framework (Engage, Explore, Explain, Engineer, Enrich, and Evaluate) to assist students solve practical problems by applying theoretical knowledge, and encourages students to build their conceptual understanding (Reiser et al., 2024; Hsiao et al., 2023). This supports the interdisciplinary learning advocated in the Next Generation Science Standards (NGSS Lead States, 2013) and further demonstrates that the application of engineering principles during physics education promotes scientific literacy. Additionally, the drastic rise in the motivation concerning STEM fields confirms the findings from the research emphasizing active learning is advantageous to student engagement. The 6E approach is hands-on and collaborative which addresses key aspects of self-determination theory—autonomy, competence, and relatedness—and therefore heightens the intrinsic motivation (Deci & Ryan, 2000; Munna and Kalam, 2021). With this learner-centered environment, promoting curiosity and persistence, findings align that project-based learning greatly enhances motivation, and interest in STEM subjects. Most literature favours design-based learning but a few studies have reported mixed results as implementation fidelity and teacher preparedness differ (Selcen et al., 2017). To fill these gaps, this study offers empirical evidence that the 6E approach is effective in a high school physics context, as well as valuable insights about its scalability and applicability.

Increase in Motivation

This study contributes theoretically and practically to STEM education and instructional design. The 6E Learning byDeSIGN™ approach to learning has proven to be successful by supporting constructivist learning theories, which state that learning occurs when learners interact actively with their environment (Piaget 1970; Vygotsky 1978). The approach facilitates experiential learning through its six dimensions: Engage, Explore, Explain, Engineer, Enrich, and Evaluate, making learners endeavour to reflect in the fashion of critical thinking beyond rhetorical interpretation reaching for deeper understanding, this also helps in perpetuating the constructivist principles of STEM education (Bruner, 1961, p. 71).

Furthermore, integrating engineering design into the science curricula, championed by Moore et al. (2014) improves content knowledge, as well as, problem-solving skills, which develops creativity and interdisciplinary skill. Students are motivated more, this is consistent with Self Determination Theory wherein 3 factors, autonomy, competence and relatedness are key to raising intrinsic motivation (Deci & Ryan, 2000). The contributions of these theoretical works highlight the role of instructional design in motivational processes in educational settings (Park, 2017). However, based on the 6E approach, educators should make an effort to increase student engagement in STEM subjects, practically; professional development programs facilitate successful implementation of the 6E approach (Bozkurt & Tan, 2021). The 6E approach can be combined with elements by curriculum developers to integrate interdisciplinary learning and the use of knowledge about real-world problems (Saritepeci & Yildiz, 2024). Policymakers must also back this up with the supply of the necessary resources and frameworks that are embedded in global trends to do with 21st-century skills like critical thinking and technological literacy.(UNESCO, 2021).

Theoretical and Practical Implications

The findings support constructivist learning theories, which emphasize knowledge construction through active engagement. Additionally, the integration of engineering design principles in science education highlights the interconnectedness of STEM disciplines, fostering creativity and problem-solving skills. From a practical perspective, these results suggest that educators should consider adopting the 6E approach to improve learning outcomes, and curriculum developers should incorporate interdisciplinary, real-world challenges into their frameworks.

Limitations

The study's limitations include its small sample size and the use of a quasi-experimental design without random assignment, which may introduce selection bias. Additionally, the short-term scope of the research limits the assessment of long-term impacts on STEM literacy and motivation. Future studies should involve larger, more diverse populations and explore the long-term effects of the 6E approach.

Conclusions

Consequently, this study demonstrates that the 6E Learning byDeSIGN™ approach dramatically enhances high school students' STEM literacy and motivation in physics education. This proved effective, and while the experimental group improved markedly over the control group, it is unknown what psychological factors contributed to this advantage. The findings are consistent with constructivist learning theories and provide practical application insights for educators and curriculum developers. Furthermore, this study gives a strong ground on which a policymaker can encourage for uptake of innovative teaching strategies in STEM education.

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References

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences, 11*(7), 331.

Ah-Nam, L., & Osman, K. (2018). Integrated STEM education: Promoting STEM literacy and 21st-century learning. *Research Highlights in STEM Education*, 66-80.

Ammar, M., Al-Thani, N. J., & Ahmad, Z. (2024). Role of pedagogical approaches in fostering innovation among K-12 students in STEM education. *Social Sciences & Humanities Open, 9*, 100839.

Baran, E., Canbazoglu Bilici, S., Mesutoglu, C., & Ocak, C. (2019). The impact of an out-of-school STEM education program on students' attitudes toward STEM and STEM careers. *School Science and Mathematics, 119*(4), 223-235.

Barry, D. M., & Kanematsu, H. (2016). *STEM and ICT education in intelligent environments*. Switzerland: Springer.

Bayanova, A. R., Orekhovskaya, N. A., Sokolova, N. L., Shaleeva, E. F., Knyazeva, S. A., & Budkevich, R. L. (2023). Exploring the role of motivation in STEM education: A systematic review. *EURASIA Journal of Mathematics, Science and Technology Education, 19*(4), em2250.

Altan, E., & Tan, S. (2021). Concepts of creativity in design-based learning in STEM education. *International Journal of Technology and Design Education, 31*(3), 503-529.

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review, 31*(1), 21-32.

Burke, B. N. (2014). THE ITEEA 6E Learning byDeSIGN™ model. *Technology & Engineering Teacher, 73*(6).

Cabrera, L., Bae, C. L., & DeBusk-Lane, M. (2023). A mixed methods study of middle students' science motivation and engagement profiles. *Learning and Individual Differences, 103*, 102281.

Chisom, O. N., Unachukwu, C. C., & Osawaru, B. (2023). STEM education advancements in Nigeria: A comprehensive review. *International Journal of Applied Research in Social Sciences, 5*(10), 614-636.

Cohen, L. (2018). *Research methods in education* (8th ed.). London: Routledge.

Çevik, M., & Bakioglu, B. (2022). The effect of STEM education integrated into teaching-learning approaches (SEITLA) on learning outcomes: A meta-analysis study. *International Journal of Progressive Education, 18*(2), 119-135.

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227-268.

Dotterer, A. M. (2022). Parent involvement, expectancy values, and STEM outcomes among underrepresented adolescents. *Social Psychology of Education, 25*(1), 113-127.

Dweck, C. S. (2016). *Mindset: The new psychology of success*. New York: Random House.

Dyrberg, N. R., & Holmegaard, H. T. (2019). Motivational patterns in STEM education: A self-determination perspective on first-year courses. *Research in Science & Technological Education, 37*(1), 90-109.

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology, 29*, 369-385.

Garriott, P. O., Hudyma, A., Keene, C., & Santiago, D. (2015). Social cognitive predictors of first-and non-first-generation college students' academic and life satisfaction. *Journal of Counseling Psychology, 62*(2), 253-266.

Hsiao, H. S., Chen, J. C., Chen, J. H., Chien, Y. H., Chang, C. P., & Chung, G. H. (2023). A study on the effects of using gamification with the 6E model on high school students’ computer programming self-efficacy, IoT knowledge, hands-on skills, and behavioral patterns. *Educational Technology Research and Development, 71*(4), 1821-1849.

Kızılay, E., Yamak, H., & Kavak, N. (2019). Motivation scale for STEM fields. *Journal of Computer and Education Research, 7*(14), 540-557.

Maknun, J. (2020). Implementation of guided inquiry learning model to improve understanding physics concepts and critical thinking skill of vocational high school students. *International Education Studies, 13*(6), 117-130.

Marchisio, M., Barana, A., Fioravera, M., Rabellino, S., & Conte, A. (2018). A model of formative automatic assessment and interactive feedback for STEM. In *2018 IEEE 42nd Annual Computer Software and Applications Conference (COMPSAC)*, Vol. 1, IEEE, 1016-1025.

Meng, N., Yang, Y., Zhou, X., & Dong, Y. (2022). STEM education in Mainland China. In *Concepts and Practices of STEM Education in Asia*, Springer Nature Singapore, 43-62.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices*, Purdue University Press, 35-60.

Munna, A. S., & Kalam, M. A. (2021). Impact of active learning strategy on student engagement. *GNOSI: An Interdisciplinary Journal of Human Theory and Praxis, 4*(2), 96-114.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Park, S. W. (2017). Motivation theories and instructional design. In *Foundations of Learning and Instructional Design Technology*.

Pintrich, P. R., Smith, D. A. F., Garcia, T., & McKeachie, W. J. (1993). Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ). *Educational and Psychological Measurement, 53*(3), 801-813.

Qian, C., Ye, J. H., & Zheng, C. (2023). Integration of Shangshan culture into the STEAM curriculum and teaching: Results of an interview-based study. *Frontiers in Psychology, 14*, 1251497.

Reiser, M., Binder, M., & Weitzel, H. (2024). Effects of design-based learning arrangements in cross-domain, integrated STEM lessons on the intrinsic motivation of lower secondary pupils. *Education Sciences, 14*(6), 607.

Ryan, R. M., & Deci, E. L. (2020). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. New York: The Guilford Press.

Sáinz, M., Fàbregues, S., Romano, M. J., & López, B. S. (2022). Interventions to increase young people's interest in STEM. *Frontiers in Psychology, 13*, 954996.

Salikha, U. A., Sholihin, H., & Winarno, N. (2021). The influence of STEM project-based learning on students’ motivation in heat transfer learning. In *Journal of Physics: Conference Series, 1806*(1), 012222. IOP Publishing.

Saritepeci, M., & Yildiz Durak, H. (2024). Effectiveness of artificial intelligence integration in design-based learning on design thinking mindset, creative and reflective thinking skills: An experimental study. *Education and Information Technologies*, 1-35.

Selcen Guzey, S., Harwell, M., Moreno, M., Peralta, Y., & Moore, T. J. (2017). The impact of design-based STEM integration curricula on student achievement in engineering, science, and mathematics. *Journal of Science Education and Technology, 26*, 207-222.

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education, 4*, 1-16.

Theobald, E. J., Hill, M. J., Tran, E., et al. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences, 117*(12), 6476-6483.

Trevissoi, M. C. (2024). Development of an innovative "hands-on physics" methodology for teaching physics at high school level.

UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. Paris, France: Educational and Cultural Organization of the United Nations.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wang, B., & Li, P. ping. (2022). Digital creativity in STEM education: the impact of digital tools and pedagogical learning models on the students' creative thinking skills development. *Interactive Learning Environments*, *32*(6), 2633–2646.

Wang, J., Li, Q., & Luo, Y. (2022). Physics identity of Chinese students before and after Gaokao: The effect of high-stake testing. *Research in Science Education, 52*(2), 675-689.

Woldeamanuel, M., Gizaw, G. & [author not specified] (2019). Motivation and attitude towards learning chemistry. *African Journal of Chemical Education, 9*, 70-88.

Yang, Y., Fan, Y., Lu, H., Yuan, H., & Xie, L. (2020). New attempt of curriculum reform: A case study of physics STEAM curriculum in a senior high school. *Research in Education, Assessment, and Learning, 6*(1), 1-14.

Yazıcı, Y. Y., Hacıoğlu, Y., & Sarı, U. (2023). Entrepreneurship, STEM attitude, and career interest development through 6E Learning byDeSIGN™ model-based STEM education. *International Journal of Technology and Design Education, 33*(4), 1525-1545.

Zhang, Y. Y. (2021). Research on STEM literacy assessment for high school students. PhD dissertation, Nanjing Normal University.

Zhong, B., Liu, X., Zhan, Z., Ke, Q., & Wang, F. (2022). What should a Chinese top-level design in STEM education look like? *Humanities and Social Sciences Communications, 9*(1), 1-8.

Zhbanova, K. (2019). Developing creativity through STEM subjects integrated with the arts. *Journal of STEM Arts, Crafts, and Constructions, 4*(1), 1.