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Shaping Spatial Minds: How School Type, Physics Achievement, and Student Motivation Influence Spatial Reasoning

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Abstract

Spatial reasoning is a fundamental cognitive skill increasingly recognized as critical for success across Science, Technology, Engineering, and Mathematics (STEM) disciplines. It underpins essential tasks in fields such as engineering, physics, architecture, and computer science, yet it remains often underdeveloped and underemphasized in traditional educational curricula. This gap presents significant challenges for students' learning and achievement in STEM pathways.

This study aimed to investigate the interplay of educational environments, physics performance, and motivational factors (including self-efficacy and attitudes toward physics) in the development of spatial reasoning skills among secondary school students. The research addressed three core questions: *(1) How do educational environments, indicated by school types, influence spatial reasoning development? (2) What is the predictive power of physics performance on spatial reasoning abilities? (3) How do students' self-efficacy and attitudes toward physics, influenced by personal and teacher factors, impact their spatial reasoning performance?*

This study employed a quantitative approach using penalized regression models (Lasso and Ridge regression) to identify key predictors of spatial reasoning performance. The sample consisted of 251 senior secondary school physics students from diverse public and private schools in Nigeria. Data were collected using validated instruments: the Mental Rotation Test (MRT) and Spatial Orientation Test (SOT) to measure spatial reasoning; a Physics Achievement Test Survey (PATS) (based on WASSCE papers) to assess physics performance; and the Students' Attitudes Toward Physics Questionnaire (SATPQ) to measure personal, teacher, and self-efficacy factors related to physics learning.

The penalized regression analyses revealed several significant predictors of spatial reasoning. School type emerged as the strongest predictor, with private school students demonstrating significantly higher spatial reasoning scores than their public school counterparts. Physics performance also showed a robust positive correlation with spatial abilities, indicating that stronger physics proficiency is associated with better performance on spatial tasks.

This study confirms the interconnected influence of educational context, domain-specific knowledge (physics), and individual motivational factors on spatial reasoning abilities. It provides empirical support for implementing curriculum reforms and pedagogical strategies that explicitly integrate spatial thinking into physics and engineering instruction, while also considering students' attitudes and self-efficacy to foster more equitable and effective STEM education. Future research should evaluate the long-term effectiveness of targeted interventions and explore the potential of digital technologies for spatial skill development.

Keywords: Spatial Reasoning, Educational Environments, Physics Performance, Self-Efficacy, and STEM

1. Introduction

Spatial ability, the capacity to visualize, manipulate, and reason about objects in space, is an essential cognitive skill in engineering and STEM education. These skills underpin critical tasks such as interpreting blueprints, solving physics problems, and developing innovative solutions to complex engineering challenges [1]. Despite their importance, spatial abilities remain underdeveloped in many educational systems, with significant disparities arising from varying school environments, teaching approaches, and students' intrinsic and extrinsic motivational factors. While previous research has explored the connections between spatial reasoning and academic success [2], particularly in STEM fields, there is a pressing need for a more robust, creative, and effective approach to cultivating spatial skills in students. This study aims to fill this gap by addressing the interplay of educational environments, physics performance, and motivational factors in developing spatial reasoning, with a focus on secondary education. Research on spatial ability has highlighted its malleability and the potential for improvement through targeted interventions [3]. Meta-analyses have shown that engaging students in spatially enriched activities, such as 3D modeling, mental rotation tasks, and physics-based visualizations, significantly enhances their spatial skills [1], [4]. However, these studies often fail to account for the influence of contextual factors such as school type and teacher-student interactions, which may mediate the effectiveness of such interventions. For instance, students in resource-rich private schools with access to advanced laboratory equipment and interactive learning opportunities often outperform their peers in under-resourced public schools, suggesting that educational environments play a crucial role in spatial ability development [5]. Yet, a systematic investigation of these contextual factors in secondary school settings is largely absent from existing literature, leaving a critical gap in understanding how educational environments shape spatial reasoning.

Physics education has emerged as a promising avenue for enhancing spatial reasoning due to its inherent reliance on mental visualization and abstract thinking. Studies have established a positive correlation between physics performance and spatial skills, noting that students who excel in physics tend to perform better on tasks requiring mental rotation and spatial orientation [6], [7]. Previous research has also shown that spatial skills can be developed through targeted interventions, particularly in physics courses, where students engage with spatially rich content such as force diagrams, vectors, and three-dimensional motion [8]. Despite this, the potential of physics education as a platform for systematically developing spatial abilities remains underexplored. Existing interventions often lack integration with physics curricula or fail to address the role of student motivation and self-efficacy, both of which are critical for sustained engagement and skill acquisition. This oversight represents a significant limitation, as motivation and self-efficacy are known to mediate students' willingness to engage with challenging spatial tasks [9], [10].

Furthermore, personal factors such as intrinsic interest and attitudes toward physics, along with teacher factors such as instructional clarity and classroom dynamics, significantly influence spatial ability development. Students with high self-efficacy and enjoyment of physics problem-solving are more likely to invest cognitive resources in spatially demanding tasks, leading to stronger spatial skills [11], [12]. However, emotional barriers such as stress and perceived difficulty can diminish these gains, particularly for students from under-resourced schools, where perceived costs of engagement are higher [13], [14]. Current literature inadequately addresses how these factors interact to influence spatial reasoning, further underscoring the need for comprehensive, multifaceted investigations.

1.1 Research Questions

Given these gaps, the present study seeks to advance engineering education research (EER) by addressing the following research questions (RQs):

1. *How do educational environments, as indicated by school type, influence the development of spatial reasoning skills in students?*
2. *To what extent does performance in physics predict spatial reasoning abilities in secondary school students?*
3. *How do students' self-efficacy and attitudes toward physics, influenced by personal and teacher factors, impact their spatial reasoning performance?*

By critically analyzing the interactions among educational environments, physics performance, and motivational factors, this study aims to provide actionable insights for enhancing spatial reasoning in engineering education. The findings will contribute to the development of targeted, context-sensitive interventions that address the unique challenges faced by diverse student populations, thereby advancing the field of EER. This investigation represents a novel contribution by integrating contextual, cognitive, and motivational dimensions to address the persistent gaps in spatial ability development, setting the stage for a transformative approach to STEM education.

2. Literature Review: Advancing Spatial Ability Development in Engineering Education

Spatial reasoning is a critical cognitive skill that underpins success in engineering and other STEM fields. Despite extensive research on its significance, gaps remain in understanding how educational environments, physics performance, and self-efficacy influence its development. This review critically synthesizes existing literature, presenting evidence to substantiate the RQs and identifying novel contributions for advancing spatial ability in EER.

2. 1 Influence of Educational Environments on Spatial Reasoning Skills

The impact of educational environments on spatial reasoning skills is a pivotal area in STEM education research. Spatial reasoning is not merely an innate ability but is malleable and influenced by the quality and resources of the learning environment. Numerous studies have demonstrated that resource-rich private schools consistently outperform under-resourced public schools in fostering spatial ability, largely due to the availability of advanced educational tools, such as 3D modeling software, CAD tools, and laboratory resources that support hands-on and visually enriched learning experiences [5], [1]. These tools not only provide students with direct exposure to spatial tasks but also enhance their ability to visualize and manipulate spatial information, a critical skill for success in STEM fields. Beyond technological resources, the quality of teacher-student interactions plays a fundamental role in shaping spatial abilities. Positive interactions, including individualized support, feedback, and encouragement, foster a sense of safety and engagement in the learning process, which is essential for tackling complex spatial reasoning tasks. Research indicates that effective classroom management and discipline contribute to creating a structured environment where students feel motivated to participate and explore spatially demanding activities [15], [16]. These factors reduce emotional barriers, such as anxiety and fear of failure, which are known to hinder cognitive performance and engagement in spatial tasks. However, the broader implications of school type on spatial reasoning development remain insufficiently explored. While private schools are often associated with superior spatial outcomes due to their resource-rich environments, the mechanisms driving these differences remain under-researched. For instance, contextual factors such as teacher training, curricular emphasis on spatial reasoning, and socioeconomic factors influencing school resources and student experiences are often overlooked in existing studies. Furthermore, public schools, particularly those in under-resourced settings, face unique challenges, including limited access to spatially enriching tools, larger class sizes, and reduced teacher-student interaction opportunities [16], [6]. Emerging research suggests that the integration of spatial reasoning tasks into regular classroom activities, irrespective of school type, can mitigate some of these disparities. For example, implementing collaborative problem-solving exercises, leveraging low-cost visual aids, and emphasizing spatial reasoning within the context of physics and mathematics curricula can create opportunities for all students to develop these critical skills [1], [4]. Additionally, systemic interventions that focus on professional development for teachers in public schools can enhance their ability to incorporate spatial reasoning tasks into their teaching practices effectively.

This study seeks to address the gaps by examining school type as a determinant of spatial reasoning development, specifically focusing on the contextual disparities between resource-rich and under-resourced environments. By investigating the mechanisms through which educational environments influence spatial abilities, this research aims to advance understanding of how to create equitable opportunities for spatial reasoning development across diverse educational settings. Such insights have broad implications for STEM education outcomes, particularly in engineering, where spatial skills are indispensable.

2.2 The Role of Physics Performance in Predicting Spatial Reasoning Abilities

The relationship between physics performance and spatial reasoning has garnered substantial attention in STEM education research. Physics inherently demands advanced cognitive processes such as visualizing forces, manipulating vectors, and predicting motion trajectories, which closely align with spatial reasoning skills [6]. These shared cognitive demands create a natural synergy, positioning physics as a key predictor of spatial ability. Numerous studies corroborate this linkage, demonstrating that students with higher physics scores perform better on spatial tasks, including the Spatial Orientation Test (SOT) and Mental Rotation Test (MRT) [7], [17]. The predictive power of physics performance in spatial reasoning lies in the deep cognitive overlaps between these domains. Tasks such as analyzing free-body diagrams, interpreting vector fields, and mentally manipulating objects require the ability to visualize spatial relationships and transformations. This connection is particularly evident in studies exploring the role of kinematics and dynamics problem-solving, where spatial visualization skills directly enhance accuracy and efficiency [6], [18]. Furthermore, physics education emphasizes abstract reasoning and conceptual clarity, which further contribute to the development of spatial abilities [4]. Despite these established connections, the causal mechanisms underlying the relationship between physics performance and spatial reasoning remains underexplored. While correlations are evident, limited research delves into how specific aspects of physics instruction, such as the integration of spatially enriched tasks, influence the development of spatial skills. Emerging evidence suggests that incorporating spatial reasoning tasks into physics curricula, such as interactive simulations and 3D modeling exercises, could amplify this relationship [1], [19]. However, these interventions are neither widespread nor systematically evaluated, leaving significant gaps in understanding their efficacy. Additionally, the extent to which self-efficacy and attitudes toward physics mediate this relationship warrants further investigation. Students who exhibit higher confidence and enjoyment in physics are more likely to engage with complex spatial tasks, fostering skill development [10], [9]. Incorporating pedagogical strategies that enhance motivation and reduce perceived barriers could therefore serve as a critical lever for spatial ability development in engineering education [17], [11].

This study addresses these gaps by quantifying the predictive value of physics performance on spatial reasoning and proposing curriculum enhancements that explicitly integrate spatial reasoning tasks into physics education. By aligning instructional practices with cognitive demands, this research seeks to advance engineering education by fostering spatial abilities critical for success in STEM disciplines.

2.3 Impact of Self-Efficacy and Attitudes Toward Physics on Spatial Reasoning

Self-efficacy and attitudes toward physics play crucial roles in the development of spatial reasoning, influencing both engagement and performance in spatially challenging tasks. Bandura's [9] self-efficacy theory posits that confidence and persistence are key drivers of success, as students who believe in their abilities are more likely to tackle complex problems with resilience. This is particularly relevant in spatial reasoning, where tasks such as mental rotation and object manipulation require sustained cognitive effort. Students with strong work ethics and enjoyment of physics problem-solving outperform their peers, as intrinsic motivation enhances cognitive resource allocation and perseverance [10], [11]. Intrinsic motivation, fostered by positive attitudes toward physics, directly supports the development of spatial abilities. Enjoyment in solving physics problems reflects an alignment of interest and capability, which facilitates deeper engagement with abstract and spatially demanding concepts. Research has demonstrated that students who find physics rewarding are more likely to invest effort in understanding spatial relationships, leading to superior performance in tests like the Spatial Orientation Test (SOT) and Mental Rotation Test (MRT) [17], [4]. Teacher behaviors significantly influence self-efficacy and spatial reasoning outcomes. Supportive teaching methods, including encouragement, individualized feedback, and clarity in instruction, build student confidence and foster a conducive learning environment for spatial skill development. Studies highlight that effective teacher-student interactions reduce emotional barriers, such as anxiety and fear of failure, which can impede engagement in spatial tasks [20], [16]. Conversely, negative interactions, such as expressing doubts about students' abilities, exacerbate emotional costs, deterring students from actively participating in spatially demanding tasks [12].

Despite these well-established relationships, current research often overlooks the integration of self-efficacy and attitudes into spatial reasoning interventions. This oversight represents a missed opportunity to design targeted educational strategies that harness these motivational and attitudinal factors. Interventions that prioritize building self-efficacy, fostering enjoyment in physics, and leveraging teacher support could significantly enhance spatial reasoning skills, particularly in under-resourced educational contexts where emotional and motivational barriers are more pronounced.

This study contributes to the field by examining how personal and teacher factors collectively shape spatial reasoning performance. By integrating self-efficacy and attitudes into spatial reasoning interventions, it offers actionable insights for EER. These insights are vital for designing pedagogical strategies that not only improve spatial skills but also address broader challenges in STEM education by promoting engagement, confidence, and motivation.

2.3.1 Synthesis and Novel Contributions

While previous studies emphasize the importance of educational environments, physics performance, and self-efficacy in spatial reasoning, they often treat these factors in isolation. This study bridges these gaps by investigating their combined effects through the lens of the RQs:

- **Educational Environments:** By explicitly analyzing school type, this study elucidates the contextual disparities in spatial reasoning development, offering targeted strategies to replicate resource-rich environments in under-resourced schools.
- **Physics Performance:** By quantifying the predictive power of physics scores and integrating spatial tasks into curricula, this study proposes innovative interventions to enhance spatial reasoning through physics education.
- **Self-Efficacy and Attitudes:** By linking self-efficacy, personal attitudes, and teacher behaviors to spatial reasoning, this research identifies actionable strategies for fostering resilience and motivation in diverse educational contexts.

This review highlights critical gaps in the literature, substantiating the need for a more robust, creative, and integrated approach to spatial ability development in engineering education. By addressing these gaps through the RQs, this study opens a new avenue for advancing EER, paving the way for transformative educational practices that equip students with the spatial skills essential for STEM success.

2.4 Penalized Regression Models: Overview and Applications

Penalized regression models are statistical techniques that introduce regularization terms into the objective function of regression models to reduce model complexity and mitigate overfitting [21], [22]. These methods are particularly effective for analyzing high-dimensional educational datasets where predictors frequently exhibit multicollinearity [23], [24]. Among the most prominent penalized regression models are Ridge regression, the Least Absolute Shrinkage and Selection Operator (LASSO), and Elastic Net. Ridge regression, which employs an L2-norm penalty, shrinks coefficients toward zero, thereby stabilizing parameter estimates and reducing multicollinearity. This approach ensures robust predictions even in the presence of highly correlated predictors, making it valuable for modeling complex relationships in educational data [23], [21]. In contrast, LASSO, which applies an L1-norm penalty, performs both regularization and variable selection by driving the coefficients of irrelevant predictors to exactly zero. This dual functionality makes LASSO particularly suitable for sparse educational datasets where identifying the most critical predictors, such as factors influencing student performance or engagement, is essential [25], [22]. Elastic Net, a hybrid method that combines L1 and L2 penalties, is especially advantageous for datasets with highly correlated predictors. By balancing coefficient shrinkage and variable selection, Elastic Net produces more stable and interpretable models. This approach is particularly relevant for studying multifactorial educational outcomes, such as spatial reasoning skills or STEM achievement, where correlated predictors are common [24], [26].

Applications of these methods in education have been diverse. For example, penalized regression models have been utilized to identify predictors of STEM success, evaluate the impact of student attitudes on learning behaviors, and understand the factors contributing to the development of cognitive skills like spatial reasoning [26], [17]. These applications underscore the utility of penalized regression in advancing educational research by providing robust, interpretable insights into high-dimensional data.

3. Theoretical Framework

This study uses Expectancy-Value Theory (EVT) to establish a framework to investigate the spatial reasoning performance of senior secondary school (K-12) STEM learners. Together, these theories provide insights into how cognitive, motivational, emotional, and selection processes influence spatial reasoning performance and persistence. This framework serves as a foundation for addressing educational inequities and informing generative AI interventions.

3.1 Expectancy-Value Theory (EVT)

EVT provides a powerful lens to explore how students' confidence in their capabilities (expectancy for success) and the value they assign to tasks (subjective task value) influence academic performance and engagement [27], [28]. The theory posits that students' beliefs about achieving success and their perceptions of the importance, interest, utility, and costs of tasks significantly shape behavior and motivation. This study underscores the importance of spatial reasoning skills, such as mental rotation and spatial visualization, as critical predictors of success in physics and other STEM disciplines. By leveraging EVT, the study offers valuable insights into how students' perceptions and beliefs influence their academic engagement and spatial reasoning development.

3.1.1 Expectancy for Success in Spatial Reasoning

The expectancy component of EVT pertains to students' confidence in completing tasks successfully. In spatial reasoning, this translates to their belief in their ability to perform complex visualization tasks, such as mental rotation, interpreting force diagrams, visualizing three-dimensional motion, or mentally rotating objects. High expectancy for success enhances persistence, enabling students to tackle spatially complex problems in STEM curricula [29], [30]. For instance, a student confident in their ability to mentally rotate objects is more likely to persist in mastering advanced geometry or CAD design, even when facing initial challenges.

3.1.2 Subjective Task Value in STEM Contexts

Subjective task value refers to the perceived relevance and utility of a task. For spatial reasoning, students' recognition of its importance in future careers - such as engineering design, architectural modeling, or data visualization - directly impacts their motivation and engagement. Students who perceive spatial skills as essential are more likely to invest effort and persist in mastering challenging tasks. By incorporating EVT constructs into the conceptual framework for spatial reasoning performance and persistence, this study emphasizes designing interventions that highlight the utility of spatial reasoning, inspiring students to prioritize its development [27], [31]. These constructs align with challenges in spatial ability assessment, where confidence, motivation, and contextual relevance play critical roles. EVT's detailed subcategories attainment value, intrinsic value, utility value, and cost provide a nuanced foundation for enhancing spatial ability measurement tools.

Table EVT. Summary of components associated with EVT

EVT Components	**Themes**	**Sub-Themes**	**Definition**
Expectancy for Success	Belief in Competence	Self-Efficacy	Expectancy for success refers to individuals' beliefs about how well they will perform on an upcoming task or activity [27].
Subjective Task Value	Importance and Motivation	Attainment Value, Intrinsic Value, Utility Value, Cost	Subjective task value represents how much a task or subject is valued by the student, including its importance (attainment), enjoyment (intrinsic), utility, and associated costs [27].
Attainment Value	Importance of Success	-	Attainment value refers to the personal importance of doing well in a task or activity, such as performing well in a technical subject like engineering mathematics [27].

Intrinsic Value	Enjoyment and Interest	-	Intrinsic value is the enjoyment or satisfaction derived from engaging in an activity or subject for its own sake, rather than for external rewards or utility [27].
Utility Value	Relevance and Usefulness	-	Utility value refers to how a task or subject contributes to future goals, such as the usefulness of engineering courses in achieving career objectives like becoming a professional engineer [27].
Cost	Opportunity Loss and Effort	-	Cost is the perceived negative aspects of engaging in a task, including time investment, effort, stress, and potential missed opportunities elsewhere [27].

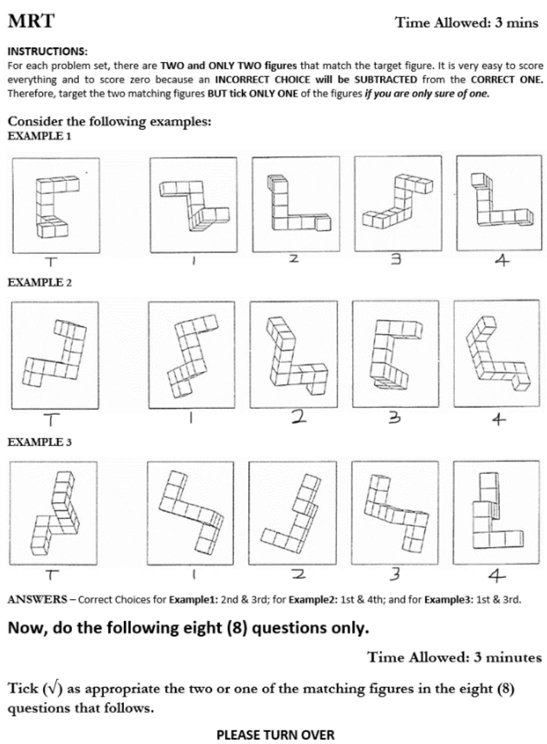
4. Methodology

4.1 Participants and Data Collection

This research engaged 251 senior secondary school (K-12) physics students from Nigeria's Ife East and Ife North Local Government Areas, encompassing a variety of educational settings across public and private institutions. The sample included 175 students from public schools and 76 from private schools, with a gender distribution of 122 females, 119 males, and 10 participants whose gender was unspecified. The average participant age was 16 years. While this geographically localized sample provides valuable insights, future research should expand to include more diverse regions and cultural contexts to improve the generalizability of findings. Socio-economic status, a potentially significant factor influencing spatial reasoning, was not examined in this study. Future investigations should incorporate socio-economic variables into a more comprehensive theoretical framework beyond EVT, offering a deeper exploration of how intersecting factors contribute to spatial reasoning development. This approach would provide a richer, context-sensitive understanding of the dynamics influencing educational outcomes across varied demographics.

4.2 Assessment Instruments and Methodological Considerations

The study employed a suite of validated instruments to evaluate physics performance, attitudes toward physics, and spatial reasoning. The Physics Achievement Test Survey (PATS), derived from past West African Senior School Certificate Examinations (WASSCE), assessed conceptual understanding and application of physics, though future studies will incorporate varied spatial reasoning measures alongside physics tasks for a more robust analysis of spatial ability. The Students' Attitudes Toward Physics Questionnaire (SATPQ) with a few of the questions presented in Table SATPQ measured personal, teacher, and self-efficacy factors, addressing self-report limitations with reverse-coded items to detect response bias. The Mental Rotation Test (MRT) (Figure 1) and Spatial Orientation Test (SOT) (Figure 2) evaluated spatial reasoning but may not fully capture the spectrum of spatial skills necessary for STEM fields, prompting recommendations to include domain-specific spatial tasks in future research. Instrument reliability was enhanced through iterative validation, though pilot testing sample sizes were limited, suggesting further reliability checks are warranted. Data collection employed a stratified sampling approach, encompassing public and private schools in the Ile-Ife East and North regions; however, the sample's limited geographical scope highlights the need for broader, more diverse samples in future studies to improve generalizability.



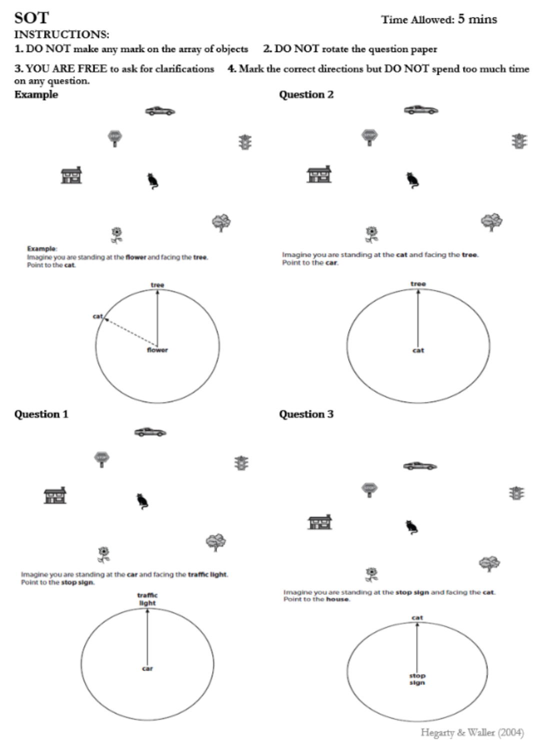


Figure 1 (Left). Sample MRT. Figure 2 (Right). Sample SOT. These screenshots display the initial pages of the two distinct tests administered to assess learners' spatial reasoning performance.

Table SATPQ. Students' Attitude Toward Physics Questionnaire (Abridged)

S/N	**ITEM**	**1**	**2**	**3**
PERSONAL FACTOR (PF)				
0	***I attend Physics classes regularly (Sample)***			
PF1	I am generally interested in learning about physics			
PF2	I have fun whenever I learn physics topics			
PF3	I learn things quickly in most physics topics			
PF4	I am interested in the things I learn in physics			
PF5	I understand everything taught in physics lesson			
PF6	The mathematics in physics often makes the subject difficult			
PF7	I only hate the calculation aspect of physics			
PF8	I prefer other subjects more than physics			

PF9	I do not see the importance of physics in everyday life			
PF10	I am happy doing physics problems			

Likert Scale: 1 – Never true 2 – Sometimes true 3 – Always true

SECTION ONE: Physics Achievement Test Survey (PATS) Questions

Dear Students,

This is an undergraduate research work aimed at determining the **"Influence of Spatial Ability on Physics Students' Learning Outcome in Senior Secondary Schools in Osun state."** Therefore, your undivided attention is crucially needed for the ***next 25 minutes*** in answering the physics questions. Please, avoid guessing and give it your best. This will provide honest answers from you that reflects your best possible performance in this test so that this research can be as genuine as it can be.

Type of School: Private ( ) Public ( ) **Gender/Sex:** Male ( ) Female ( ) **Class:** SSS1 ( ) SSS2 ( ) SSS3 ( )

INSTRUCTION: Attempt All Questions

Objective Questions Only

1. The slope of a straight line displacement-time graph indicates the (a) Distance traveled (b) Uniform Velocity (c) Uniform acceleration (d) Acceleration at an instant (e) Uniform speed
2. Which of the following are contact force? I Force of tension II Force of friction III Magnetic force IV Force of reaction. (a) I, II and III only (b) I, II and IV only (c) I, III and IV (d) II, III and IV only (e) I and IV only
3. A ball is thrown vertically upward from the ground with an initial velocity of $50ms^{-1}$. What is the total time spent by the ball in the air? (a) 2.5s (b) 5.0s (c) 10.0s (d) 15.0s (e) 20.0s
4. A boy pulls a nail from the wall with a string tied to the wall. The string is inclined at an angle of 60° to the wall. If the tension in the string is 4N, what is the effective force used in pulling the nail? (a) 2N (b) $2\sqrt{3}N$ (c) 4N (d) $4\sqrt{3}N$ (e) 8N
5. A piece of cork which is floating on water is acted upon by the force of: (a) weight and viscosity (b) weight and upthrust (c) upthrust and viscosity (d) weight only (e) upthrust only
6. Which of the following is a derived unit? (a) Metre (b) Second (c) Kilograme (d) Coulomb (e) Ampere
7. A fixed mass of gas of volume 600 cm^3 at a temperature of 27^0C is cooled at constant pressure to a temperature of 0^0C. What is the change in volume? (a) 54 cm^3 (b) 273 cm^3 (c) 300 cm^3 (d) 546 cm^3 (e) 600 cm^3
8. Which of the following instruments is suitable for making the most accurate measurement of the internal diameter of a test tube? (a) Metre rule (b) A micrometer screw gauge (c) A pair of calipers (d) A tape (e) A set of squares
9. A body accelerates uniformly from rest at the rate of $3ms^{-2}$ for 8 seconds. Calculate the distance covered by the body during the acceleration. (a) 12m (b) 24m (c) 48m (d) 72 (e) 96m
10. A body of mass 5kg falls from a height of 10m above the ground? What is the kinetic energy of the body just before it strikes the ground? (Neglect energy losses and take $g = 10ms^{-2}$). (a) 5J (b) 25J (c) 250J (d) 500J (e) 625J

Figure 3. *The screenshot displays the instruction section and the first 10 out of the total 20 objective test questions administered to assess learners' physics performance.*

4.3 Data Analysis

LASSO and Ridge regression models were applied to identify the predictors of spatial reasoning. The primary dependent variables were the SOT and MRT scores, while the independent variables included school type, physics performance, and personal factors (PF), teacher factors (TF), and self-efficacy factors (SEF) from the SATPQ. The predictive models were used to examine the relative contribution of each predictor to spatial reasoning performance due to their ability to handle multicollinearity and for their capacity to select important predictors from a large set of variables.

4.4 Model Interpretation

The coefficients from the LASSO and Ridge models were analyzed to determine the most influential predictors of spatial reasoning. Features with higher coefficients were interpreted as having a stronger relationship with the target variables, while those with lower or negative coefficients were seen as less influential.

5. Results

5.1 Analysis of Coefficients and Features in Predictive Models

The analysis of coefficients from the Lasso and Ridge models reveals critical insights into factors influencing students' spatial orientation and mental rotation abilities as measured by the Spatial Orientation Test (SOT) and Mental Rotation Test (MRT). Key coefficients – quantitative measures of the influence of each predictor – highlight the significant roles of school type, physics performance, and individual engagement. School type (SCHLTYPE, Coefficient = 0.318917) is the most influential predictor across both models. The positive coefficient suggests that students from certain school types, likely those with better teaching methods and resources, achieve higher spatial orientation and mental rotation scores. This aligns with factors such as teacher-student interaction (TF1) and clear explanations of complex concepts (TF5) in educational settings. Physics performance (PHYSICS SCORE, Coefficient = 0.186734) also significantly correlates with spatial abilities in both tests. The coefficient highlights that students excelling in physics, a subject requiring spatial reasoning and mental manipulation, perform better on these spatial tasks. This relationship may be strengthened by interest and confidence in physics (PF3, SEF10). Personal factors such as understanding physics concepts (PF5, Coefficient = 0.137586) and enjoying physics problem-solving (PF10, Coefficient = 0.136615) exhibit robust positive effects. The coefficients show that students who comprehend and enjoy physics are better at spatial orientation and mental rotation, likely due to improved cognitive visualization and engagement. Self-efficacy factors, notably effort in studying physics (SEF8, Coefficient = 0.173915), underscore the role of persistence. A higher coefficient for SEF8 indicates that students who work diligently on physics topics exhibit enhanced spatial skills, demonstrating the importance of hard work in developing cognitive abilities. These coefficients collectively emphasize that school type (SCHLTYPE, 0.318917), physics scores (PHYSICS SCORE, 0.186734), and cognitive engagement in physics (PF5, 0.137586; PF10, 0.136615) are pivotal in predicting spatial performance. This quantitative insight enables targeted educational strategies to foster spatial reasoning by improving school environments, nurturing interest in physics, and promoting self-efficacy.

6. Discussion

This section provides a detailed examination of the predictors influencing spatial reasoning skills, focusing on insights derived from Lasso and Ridge regression models.

6.1 The Impact of Educational Environment on Spatial Reasoning

The role of educational environments in developing spatial reasoning is critical to advancing engineering education research (EER). The analysis of spatial reasoning performance, as measured by the Spatial Orientation Test (SOT) and Mental Rotation Test (MRT), reveals that school type is the strongest predictor. Students attending private schools consistently outperformed their counterparts in public schools, suggesting that educational environments with superior resources and interactive learning opportunities better support the development of spatial skills. These findings resonate with prior research indicating that problem-solving and hands-on learning environments foster stronger spatial abilities [5]. Private schools' significant positive impact, as captured by the coefficient for school type (SCHLTYPE), reflects their ability to provide enriched educational experiences. These schools often feature better teacher-student interactions and clearer, more engaging instructional methods, as supported by data from the Students' Attitudes Toward Physics Questionnaire (SATPQ). Specifically, teacher interaction (TFI) and the ability to deliver complex explanations effectively (TF5) emerge as pivotal factors in enhancing spatial reasoning. Such insights are consistent with findings that exposure to spatially enriched environments, including access to tools like 3D modeling software and laboratory equipment, can significantly enhance spatial cognitive abilities [1]. The implications for EER are profound. The evidence underscores the importance of replicating resource-rich, interactive environments found in private schools within under-resourced public schools. Interventions aimed at incorporating problem-based learning, hands-on activities, and access to advanced technological tools could democratize the benefits of enriched educational contexts, addressing inequities in cognitive development opportunities. Furthermore, these findings align with broader educational theories emphasizing the interplay between resources, instructional quality, and cognitive development. The data-driven insights affirm that well-supported school environments not only improve spatial reasoning but also foster essential skills relevant for engineering disciplines, such as visualization and mental manipulation of objects. By focusing on these transformative educational factors, EER can chart a path toward innovative and equitable pedagogical strategies. In conclusion, the analysis highlights school type as a critical determinant of spatial reasoning ability, reflecting the transformative impact of resource-rich, interactive educational environments. These findings present a compelling case for systemic interventions in education to ensure all students have access to high-quality, spatially enriching learning experiences, thereby advancing cognitive skill development and contributing to the broader goals of engineering education.

6.2 Role of Physics Performance in Predicting Spatial Abilities

Physics performance has been identified as a pivotal predictor of spatial reasoning abilities, as measured by the Spatial Orientation Test (SOT) and Mental Rotation Test (MRT). Students with higher physics scores consistently demonstrated superior spatial reasoning skills, underscoring the inherent overlap between physics and spatial cognition. This finding aligns with prior research indicating that strong spatial abilities are crucial for solving kinematics problems and visualizing motion in space [6]. The positive correlation between physics performance and spatial reasoning highlights the potential of leveraging physics education to enhance cognitive flexibility required for tasks such as mental rotation and spatial orientation. Physics inherently involves mental visualization of abstract concepts such as forces, vectors, and motion, making it an ideal domain for cultivating spatial reasoning. For instance, integrating spatial reasoning exercises into physics curricula such as visualizing forces, manipulating vectors, and solving problems involving three-dimensional motion can strengthen this critical cognitive skill [6]. Insights from the Students' Attitudes Toward Physics Questionnaire (SATPQ) further reveal the nuanced role of students' attitudes toward physics in shaping spatial reasoning abilities. Factors such as enjoyment of physics topics (PF3), interest in physics (PF1), and confidence in solving physics problems (SEF10) emerged as important contributors to performance. These findings suggest that fostering a positive and engaging learning environment in physics not only boosts academic performance but also facilitates the development of spatial skills critical for engineering and computational disciplines. In conclusion, the strong linkage between physics performance and spatial reasoning presents a compelling case for incorporating targeted spatial training into physics education. By doing so, educators can create a dual benefit of improving physics comprehension while enhancing the spatial skills necessary for success in STEM fields. This intersection between physics education and spatial reasoning offers a promising avenue for advancing engineering education research and addressing the cognitive demands of future engineers.

6.3 EVT Constructs and Spatial Ability Development

6.3.1 The Influence of Self-Efficacy and Attitudes Toward Physics

Self-efficacy and positive attitudes toward physics are central to the development of spatial reasoning skills, as evidenced by their substantial contributions to Spatial Orientation Test (SOT) and Mental Rotation Test (MRT) performance. Intrinsic motivation and persistence, captured by SEF8 (students' work ethic in studying physics), emerge as critical predictors of spatial reasoning ability. Students who exhibited strong effort "working as hard as possible" - consistently outperformed their peers, underscoring the vital role of persistence in mastering spatially challenging tasks. This aligns with Bandura's [9] self-efficacy theory, which posits that individuals with confidence in their abilities are more likely to engage in demanding tasks requiring resilience and sustained effort. The enjoyment of physics problem-solving, encapsulated in PF10, further highlights the impact of positive attitudes on spatial reasoning. Students who expressed enjoyment in solving physics problems demonstrated superior spatial reasoning performance, reflecting their comfort with abstract thinking and mental manipulation. Prior studies affirm that intrinsic motivation enhances engagement with spatially demanding tasks, fostering stronger spatial abilities [11]. Similarly, conceptual clarity in physics, represented by PF5 (understanding all material taught in physics lessons), proved to be another crucial determinant of spatial reasoning.

Students with a comprehensive grasp of physics principles performed significantly better in spatial assessments, emphasizing the interdependence of physics comprehension and spatial reasoning. This relationship underscores the importance of integrating physics-based learning frameworks to support the development of spatial skills in engineering education. Self-efficacy factors (SEF) further encompass students' confidence, emotional responses, and persistence, all of which are instrumental in shaping spatial ability. EVT provides a comprehensive framework to understand how expectancy and task value beliefs interact with self-efficacy to influence engagement and achievement. Negative emotional responses, including stress, nervousness, and helplessness (SEF1-SEF4), act as significant barriers by amplifying the perceived cost of spatial reasoning tasks. These barriers disproportionately affect students from under-resourced environments, highlighting the need for interventions aimed at reducing stress and building resilience [12], [14]. Perceived difficulty (SEF5-SEF7) further compounds these challenges, with low expectancy beliefs intensifying disengagement. Conversely, students with high self-efficacy exhibit greater persistence and effort (SEF8-SEF10), demonstrating the importance of goal-driven resilience in overcoming spatial reasoning difficulties [9].

6.3.2 The Role of Personal Factors in Spatial Ability Development

Personal Factors (PF), encompassing intrinsic motivations, attitudes, and perceptions, play a pivotal role in shaping student engagement and performance in spatial reasoning tasks, a critical area for STEM education and engineering education research (EER). The EVT provides a robust framework for understanding how expectancy for success and subjective task value drive spatial reasoning, offering actionable insights into leveraging these factors to enhance STEM learning outcomes. Students' interest and enjoyment in learning physics (PF1-PF4) align with the EVT construct of intrinsic value, reflecting the innate curiosity that sustains engagement with spatially demanding tasks. Research demonstrates that fostering intrinsic interest significantly enhances spatial reasoning skills, as students willingly invest cognitive resources in challenging tasks when driven by genuine curiosity and enjoyment [10], [17]. This relationship underscores the importance of designing physics curricula and activities that stimulate and sustain intrinsic motivation. Additionally, understanding physics concepts (PF5) corresponds to expectancy beliefs, a cornerstone of EVT, which predicts confidence and subsequent performance in spatial tasks. Students with high confidence in their understanding of physics principles exhibit greater proficiency in spatial reasoning, as they approach tasks with optimism and a readiness to engage [32]. However, perceived barriers, such as the mathematical complexities inherent in physics (PF6-PF7), introduce significant challenges. Students experiencing high perceived costs often disengage unless offset by strong intrinsic interest or utility value [13], [29]. Moreover, preferences for other subjects (PF8- PF9) demonstrate the influence of low attainment value and perceived costs in detracting from spatial ability development. Emphasizing the career relevance of physics and STEM disciplines (PF13-PF15) is essential in addressing this issue. Recognizing the utility value of spatial reasoning in STEM careers can bolster students' motivation and expectancy for success, further integrating spatial skills into their academic and professional goals [33]. In conclusion, personal factors, when aligned with the constructs of EVT, offer a comprehensive lens for advancing EER. Strategies that enhance intrinsic interest, bolster expectancy beliefs, and emphasize the utility value of spatial reasoning hold the potential to significantly improve spatial skills development. These findings underscore the need for targeted interventions to address perceived barriers, foster engagement, and connect physics and STEM education to broader career goals, thereby equipping students with the cognitive tools required for success in engineering disciplines.

6.3.3 Teacher Factors as Determinants of Spatial Ability

Teacher Factors (TF) play a critical role in shaping the contextual determinants of students' spatial reasoning abilities, offering valuable insights for advancing EER. The EVT provides a robust framework to explore how teacher behaviors, instructional methods, and attitudes influence student engagement, self-efficacy, and motivation. Positive teacher-student interactions, including supportive communication and effective classroom discipline (TF1-TF2), are essential for fostering an environment conducive to spatial reasoning. These factors enhance students' expectancy for success by reducing the emotional cost associated with engagement in challenging spatial tasks. Research demonstrates that constructive teacher behaviors build confidence and motivation, encouraging students to persist in cognitively demanding activities [15]. Conversely, negative teacher behaviors, such as abusive language (TF3) or expressing doubts about student capabilities (TF4), significantly undermine self-efficacy. These behaviors increase the emotional cost of participation, resulting in disengagement from spatial tasks. Such detrimental effects underscore the importance of cultivating positive social influences in the classroom to support the development of spatial reasoning skills [20]. Instructional clarity (TF5) emerges as a cornerstone of effective teaching, particularly in advancing spatial ability. Clear, relatable, and structured explanations enhance students' understanding of complex spatial concepts, thereby improving their attainment and utility value for these skills. This clarity fosters higher engagement and confidence, making abstract concepts more accessible and attainable. Hattie [16] emphasizes that instructional clarity is among the most impactful teaching strategies for improving student outcomes, highlighting its critical role in engineering education. In conclusion, teacher factors significantly influence students' spatial reasoning through their impact on classroom dynamics, emotional costs, and instructional effectiveness. By prioritizing supportive teacher behaviors, minimizing negative interactions, and ensuring instructional clarity, educators can create learning environments that enhance spatial skills. These insights provide a roadmap for integrating teacher-focused strategies into EER, ultimately contributing to more effective and equitable STEM education.

7. Implications for Engineering and STEM Education

7.1 Enhancing Curriculum Design

The findings of this study underscore the critical need to integrate spatial reasoning tasks into engineering and STEM curricula. Incorporating activities such as mental rotation exercises, 3D modeling projects, and visualization-based problem-solving into physics courses can foster the cognitive skills essential for success in these disciplines. Providing access to spatially enriched environments, such as laboratories equipped with 3D printers, CAD software, or virtual reality simulations, further amplifies the potential for spatial skills development. These interventions are particularly impactful when combined with clear and engaging instructional methods, as they foster self-efficacy and intrinsic motivation among students.

7.2 Early and Sustained Interventions

The strong relationship between physics performance and spatial reasoning highlights the importance of initiating targeted interventions early in students' academic trajectories. Spatial reasoning tasks should be introduced in secondary school physics curricula to equip students with foundational cognitive skills for engineering and STEM pathways. Such early interventions are especially crucial for students in under-resourced schools, where disparities in access to spatially enriched environments and advanced educational tools may impede skill development. Strategies that integrate career relevance and intrinsic value into physics education can further enhance engagement and motivation, creating a pathway for sustained cognitive growth.

8. Conclusion and Future Research Directions

This study demonstrates that educational environments, physics performance, and self-efficacy collectively shape spatial reasoning abilities. The findings suggest that targeted improvements in physics education could enhance spatial reasoning, yielding broader benefits for STEM and engineering education. Future research should examine the long-term impact of spatial reasoning interventions and explore innovative teaching strategies tailored to diverse educational contexts. Additionally, investigating the role of digital technologies, such as virtual and augmented reality, in fostering spatial skills offers a promising avenue for advancing engineering education research and practice.

References

[1] D. H. Uttal, N. G. Meadow, L. L. Hand, A. R. Alden, C. Warren, and M. G. Boilen, "The malleability of spatial skills: A meta-analysis of training studies," *Psychological Bulletin*, vol. 139, no. 2, pp. 352–402, 2013.

[2] S. A. Sorby, "Spatial training and its effect on student academic success," *Engineering Design Graphics Journal*, vol. 73, no. 2, pp. 12-20, 2009.

[3] S. A. Sorby and N. L. Veurink, "Enhancing spatial skills: Preparing STEM students for the 21st Century," *SAHARA: A Journal of the Social and Human Sciences*, vol. 2, no. 2, 2010.

[4] J. Wai, D. Lubinski, and C. P. Benbow, "Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance," *Journal of Educational Psychology*, vol. 101, no. 4, pp. 817-835, 2009.

[5] I. Marunić and V. Glažar, "The influence of school type on the development of spatial ability," *Croatian Journal of Education: Hrvatski časopis za odgoj i obrazovanje*, vol. 16, no. 4, pp. 1063-1082, 2014.

[6] M. Kozhevnikov, M. A. Motes, and M. Hegarty, "Spatial visualization in physics problem solving," *Cognitive Science*, vol. 31, no. 3, pp. 489-520, 2007.

[7] A. Edelyn, S. Suparmi, and J. Handhika, "The correlation between spatial ability and physics problem solving ability of senior high school students," *Journal of Science Education and Learning*, vol. 2, no. 1, pp. 1-8, 2013.

[8] S. E. Miller and D. F. Halpern, "Effects of teaching spatial skills on subsequent performance in a university-level calculus-based physics course," *Physics Education Research Conference*, 2011.

[9] A. Bandura, *Self-efficacy: The exercise of control*. W. H. Freeman, 1997.

[10] R. M. Ryan and E. L. Deci, "Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being," *American Psychologist*, vol. 55, no. 1, pp. 68-78, 2000.

[11] B. Ibrahim and N. S. Rebello, "Students' epistemic framing for solving physics problems and its relation to self-efficacy and spatial ability," *Physical Review Special Topics-Physics Education Research*, vol. 8, no. 1, p. 010125, 2012.

[12] F. Pajares, "Self-efficacy beliefs in academic settings," *Review of Educational Research*, vol. 66, no. 4, pp. 543-578, 1996.

[13] A. Wigfield, S. Tonks, and S. L. Klauda, "Expectancy-value theory," in *Handbook of motivation at school*, 2nd ed., K. R. Wentzel and D. B. Miele, Eds. Routledge, 2016, pp. 55-74.

[14] B. J. Zimmerman, "Attaining self-regulation: A social cognitive perspective," in *Handbook of self-regulation*, M. Boekaerts, P. R. Pintrich, and M. Zeidner, Eds. Academic Press, 2000, pp. 13-39.

[15] M. Kunter, Y. M. Tsai, U. Klusmann, M. Brunner, T. Voss, and J. Baumert, "Students' engagement and intrinsic learning motivation: Profiles and relations to academic achievement," *Journal of Educational Psychology*, vol. 105, no. 2, pp. 456-468, 2013.

[16] J. Hattie, *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. Routledge, 2009.

[17] S. Wang, J. Chen, J. Dai, and L. Liu, "The relationship between spatial ability and academic performance in physics," *International Journal of Science Education*, vol. 40, no. 12, pp. 1403-1418, 2018.

[18] M. Hegarty and D. Waller, "Portraits of a spatial learner," *Educational Psychology Review*, vol. 17, no. 3, pp. 243-259, 2005.

[19] N. S. Newcombe, "Synthesis: Seeing relationships: The fundamental role of spatial reasoning in STEM education," *Cognitive Research: Principles and Implications*, vol. 1, no. 1, pp. 1-11, 2016.

[20] H. R. Korpershoek, H. Kuyper, J. Caspersen, and T. Wubbels, "Student perception of teacher-student interaction and academic achievement: A meta-analysis of studies in middle and secondary schools," *Educational Research Review*, vol. 13, pp. 74-87, 2014.

[21] J. Friedman, T. Hastie, and R. Tibshirani, *The elements of statistical learning*. Springer, 2001.

[22] T. Hastie, R. Tibshirani, and M. Wainwright, *Statistical learning with sparsity: The Lasso and generalizations*. CRC press, 2015.

[23] A. E. Hoerl and R. R. Kennard, "Ridge regression: Biased estimation for nonorthogonal problems," *Technometrics*, vol. 12, no. 1, pp. 55-67, 1970.

[24] H. Zou and T. Hastie, "Regularization and variable selection via the elastic net," *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, vol. 67, no. 2, pp. 301-320, 2005.

[25] R. Tibshirani, "Regression shrinkage and selection via the lasso," *Journal of the Royal Statistical Society: Series B (Methodological)*, vol. 58, no. 1, pp. 267-288, 1996.

[26] R. Ahmed and K. VanLehn, "Predicting performance and engagement in a university STEM course using behavioral and process data," *User Modeling and User-Adapted Interaction*, vol. 33, no. 4, pp. 707-741, 2023.

[27] A. Wigfield and J. S. Eccles, "Expectancy-value theory of achievement motivation," *Contemporary Educational Psychology*, vol. 19, no. 1, pp. 107-118, 1994.

[28] M. T. Wang and J. L. Degol, "Motivational pathways to STEM success: Expectancy–Value Theory in STEM education," in *Handbook of motivation at school*, 2nd ed., K. R. Wentzel and D. B. Miele, Eds. Routledge, 2020, pp. 98-121.

[29] J. S. Eccles, "Subjective task value and the Eccles et al. model of achievement-related choices," in *Handbook of competence and motivation*, A. J. Elliot and C. S. Dweck, Eds. Guilford Press, 2005, pp. 105-123.

[30] K. Li, S. Zhang, and J. He, "Expectancy-value theory and STEM career aspirations: The role of achievement goals and perceived parental support," *Frontiers in Psychology*, vol. 12, p. 665339, 2021.

[31] Y. Zhao, Y. Xu, J. Du, J. Fan, and R. Liu, "Factors influencing college students' learning engagement in online STEM courses: An Expectancy-Value Theory perspective," *Frontiers in Psychology*, vol. 14, p. 1103111, 2023.

[32] D. H. Schunk, "Self-efficacy and academic achievement," *Educational Psychologist*, vol. 26, no. 3-4, pp. 207-231, 1991.

[33] A. Byars-Winston, Y. Estrada, C. Howard, D. Davis, and M. Sweeney, "Influence of perceived STEM barriers on STEM efficacy, interest, and pursuit: An exploratory study of racially/ethnically diverse students," *Journal of Career Assessment*, vol. 23, no. 3, pp. 447-463, 2015.