

# Transforming STEM Pedagogy through Observation-Driven Learning: An Astronomy Case Study

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## ABSTRACT

Transforming STEM pedagogy from theoretical education to substantive learning continues to pose a problem, especially in underfunded institutions. This study looks at a hands-on learning method used in an astronomy curriculum to address poor understanding and low student interest in STEM subjects. The study aimed to evaluate the effectiveness of direct celestial observation in enhancing STEM understanding. A descriptive pre-post approach was utilized, employing structured questionnaires delivered before to and during a university-school outreach intervention that included guided telescope viewing and incorporated STEM activities. The data were analyzed utilizing frequency and percentage metrics. The results demonstrate significant enhancements in students' comprehension of STEM subjects after engaging in the program, implying the potential efficacy of observation-based learning in a rural educational setting. The research finds that observation-based astronomy education is an excellent teaching technique for improving STEM education in rural and resource-constrained environments.

**Keywords:** astronomy, STEM, pedagogy, observation-driven, secondary student

## INTRODUCTION

The increasing focus on science, technology, engineering, and mathematics (STEM) education underscores its essential function in equipping individuals for engagement in knowledge-based and technology-oriented societies. Global policy frameworks and educational changes constantly emphasize STEM proficiency as crucial for economic sustainability, innovation, and social advancement [1], [2]. Notwithstanding these aims, enduring obstacles exist in converting STEM courses into significant learning experiences, especially in secondary school settings where instruction frequently remains theoretical and examination-focused.

A persistent issue in STEM education studies is students' inadequate conceptual understanding and challenges in correlating symbolic representations with real-world occurrences [3], [4]. This problem is particularly evident in underfunded and rural schools, where access to labs, scientific equipment, and practical learning possibilities is limited [1]. Consequently, numerous students see STEM disciplines as intellectually taxing, unengaging, and irrelevant to daily life, resulting in diminished motivation and involvement.

Recent literature has increasingly endorsed experiential and inquiry-based pedagogies as appropriate solutions to these difficulties. Experiential learning theory asserts that knowledge is formed via direct experience, reflection, and application, allowing learners to cultivate a deeper and more transferable understanding [5]. Empirical research in STEM education has shown that learning settings based on observation, experimentation, and practical interaction markedly improve students' conceptual comprehension, scientific reasoning, and attitudes toward STEM [6], [13].

In this educational transition, observation-based learning has surfaced as a potential methodology. Observation-driven learning prioritizes direct interaction with observable events as the foundation of education, enabling learners to ground abstract concepts in sensory and empirical experiences [7]. This method strongly coincides with genuine scientific activity, wherein observation serves a fundamental role in inquiry, hypothesis development, and explanation. This study prioritizes instructional understanding within a rural,

under-resourced environment, which is underrepresented in STEM education research, rather than pursuing wide generalizability.

### **Astronomy In Stem Learning**

Astronomy offers a particularly powerful context for observation-driven STEM learning. As an inherently interdisciplinary field, astronomy integrates physics, mathematics, spatial reasoning, and technology, while providing accessible and compelling observable phenomena (Bailey & Slater, 2022). Research has shown that astronomy-based learning experiences can enhance student engagement, support conceptual change, and foster positive STEM identities, especially when learners participate in guided observation using telescopes or sky-mapping tools (Plummer & Small, 2019; Bretones & Compiani, 2021).

However, despite its pedagogical potential, astronomy remains underutilised as a core instructional strategy in formal STEM education, particularly in Global South and rural contexts. Most existing studies on astronomy education are situated in Western or urban settings, leaving a gap in empirical evidence regarding its effectiveness as a pedagogical tool in resource-limited schools (Bailey et al., 2020; UNESCO, 2021).

To address this gap, the present study investigates how an observation-driven learning approach, implemented through an astronomy-based program, can contribute to transforming STEM pedagogy in a secondary school setting. Through a case study conducted in a rural Malaysian school via a university–school partnership, this research examines the extent to which direct astronomical observation supports conceptual clarity, engagement, and meaningful STEM learning. By providing empirical evidence from an underrepresented educational context, the study contributes to ongoing discussions on pedagogical innovation, experiential learning, and equitable STEM education.

### **Stem Pedagogy**

This study demonstrates the increasing agreement that deep conceptual comprehension and persistent learner engagement cannot be fostered by traditional STEM education, which places a higher priority on abstract instruction and symbolic representations. Recent studies repeatedly indicate that students find it challenging to relate mathematical formalisms and theoretical concepts to real-world occurrences, leading to a fragmented knowledge and diminished trust in STEM education [1], [3]. These issues are especially pronounced in rural and underfunded educational settings, where access to labs, scientific instruments, and enrichment activities is severely restricted [2], [12].

A significant corpus of research endorses the transition to experiential and active learning methodologies as a remedy for these educational constraints. Experiential learning theory asserts that information is developed via direct experience, reflection, and application, rather than through passive receiving. Empirical research in STEM fields indicates that active and experiential pedagogies markedly enhance student performance, conceptual memory, and motivation relative to conventional lecture-based education [6]. The literature therefore offers a robust theoretical basis for instructional methods that prioritize experience and interaction as essential to learning.

In this comprehensive experiential framework, observation-based learning has proven to be a very successful approach for tackling conceptual challenges in STEM education. Observation is a core epistemic activity in science, underpinning inquiry, hypothesis formulation, and evidence-based reasoning. Studies in science education demonstrate that students who interact directly with observable events cultivate enhanced conceptual coherence and are more adept at aligning scientific models with empirical data [7], [8]. This corresponds with results that observation-based training facilitates conceptual transformation by addressing misunderstandings and grounding abstract concepts in perceptual experience.

Astronomy is frequently recognized in the literature as a potent integrative framework for observation-based STEM education. The multidisciplinary character facilitates the amalgamation of physics, mathematics, spatial thinking, and technology into a unified teaching framework [9], [10]. Observational astronomy allows learners to participate in genuine scientific procedures using actual instruments, such as telescopes, hence improving cognitive and emotional learning outcomes. Research indicates that astronomy-focused educational

experiences enhance student engagement, foster scientific thinking, and reinforce favorable views toward STEM fields [7], [9].

Notwithstanding these benefits, the evidence indicates a notable deficiency in the systematic incorporation of astronomy within formal STEM education, particularly within non-Western and rural educational settings. The majority of empirical research on astronomy education occurs in urban or resource-abundant settings, constraining the generalizability of their results [9], [10]. Moreover, whereas outreach projects are often documented, there is a scarcity of research that investigate their pedagogical ramifications or assess how observation-based astronomy education might facilitate enduring changes in STEM teaching methodologies [11].

A significant subject arising from the literature pertains to educational equity and access. Students in rural areas may have systemic disadvantages, such as insufficient access to scientific role models and diminished possibilities for experiential learning [1], [12]. University-school collaborations are widely acknowledged as viable means to alleviate these inequities by spreading expertise, infrastructure, and instructional innovation beyond higher education institutions. The literature demands further empirical data illustrating how these collaborations might stably improve classroom pedagogy instead of only serving as transient enrichment projects.

The literature emphasizes the necessity for instructional methods that incorporate experiential learning, genuine scientific practices, and contextual significance. Although previous studies demonstrate the theoretical and practical advantages of observation-driven and astronomy-based STEM teaching, there is a deficiency of case-based data showcasing the implementation of these methods in rural secondary school environments. This project investigates observation-driven learning in astronomy to revolutionize STEM education, therefore enhancing current scholarship and providing empirical insights from a Global South perspective.

## **METHODOLOGY**

The study approach used to investigate how astronomical outreach programs affect secondary students' interest in STEM is described in the methods section. To guarantee objective and quantifiable outcomes, a quantitative research strategy was used, offering statistical support for evaluating shifts in student engagement, knowledge acquisition, and career goals in STEM subjects. To assure validity and reliability, this study uses a well-defined sample selection procedure, a systematic approach to data collecting, a structured research design, and rigorous data analysis methodologies.

The study focuses on assessing outreach programs related to astronomy, including knowledge sharing, interactive astronomy experiments, hands-on observational activities, and solar observation or stargazing activities. This study evaluates students' views about STEM disciplines both before and after they take part in outreach initiatives using a quasi-experimental pretest-posttest approach. Surveys and statistical analyses were among the quantitative techniques used to evaluate shifts in learning outcomes and student involvement. To guarantee a thorough grasp of the outreach programs' efficacy, information was collected from secondary school pupils in a variety of regional and socioeconomic contexts.

This study's methodological approach shows a conscious match between the goals of the research and the practicalities of assessing pedagogical innovation in real-world educational environments. Considering the study's main objective, to assess the educational efficacy of an observation-driven, astronomy-focused STEM intervention, the implementation of a descriptive pre-post research design is both suitable and methodologically sound. Recent educational research has highlighted that descriptive and quasi-experimental methods are especially appropriate for outreach and school-based interventions, where randomization and control groups are frequently unfeasible or morally limited [14], [15].

This research utilizes a case study technique to facilitate a comprehensive analysis of pedagogical transition in a particular school setting. Case studies are acknowledged as essential methodological instruments in STEM education research aimed at comprehending the mechanisms and rationale behind the effectiveness of educational innovations in practical settings [15]. The study emphasizes contextual validity and ecological

realism by concentrating on a rural secondary school, which are increasingly highlighted in modern STEM teaching methodologies [3].

The choice of pre–post questionnaire instruments as the principal data gathering approach aligns with known methods in assessing educational interventions. Survey-based instruments are frequently employed to assess alterations in learners' conceptual comprehension, abilities, attitudes, and perceptions across time [17]. This study utilized a structured questionnaire specifically created to correspond with the intervention's learning objectives, hence assuring content validity. The incorporation of elements assessing conceptual clarity, practical abilities, and engagement aligns with contemporary suggestions for a comprehensive evaluation of STEM learning that transcends only cognitive results [4].

The focus on frequency and percentage analysis signifies a deliberate analytical decision. Descriptive statistical methods are especially suitable when the study aim is to discern patterns of change and the extent of improvement, rather than to determine causal relationships [18]. Frequency-based analysis facilitates transparent reporting of educational alterations, making them clearly interpretable by educators, policymakers, and practitioners within the framework of pedagogical innovation and outreach assessment [19]. This method is being promoted in STEM education research to improve accessibility and practical significance of findings, particularly for educational stakeholders.

The choice to utilize pre–post percentage change ( $\Delta\%$ ) analysis enhances methodological rigor by offering a clear depiction of learning gains across various domains. Comparative descriptive metrics are extensively employed in educational research to illustrate the effects of interventions while preventing overgeneralization [20]. The study reports outcomes as ranges and proportionate changes, conforming to best practices that advise avoiding exaggerating efficacy in non-experimental designs [1], [14].

A significant methodological feature of this study is its congruence between teaching and assessment. Observation-driven learning prioritizes experiential engagement, conceptual clarity, and practical competence; hence, employing learner self-reports that concentrate on perceived comprehension and confidence is methodologically sound. Previous research indicates that meticulously developed and contextualized self-reported measures yield reliable insights into students' learning experiences and pedagogical effects, especially in exploratory and formative investigations [21].

Nonetheless, the technique demonstrates an acknowledgment of its intrinsic limits. The lack of a control group limits the capacity to ascribe observed changes exclusively to the intervention, a limitation recognized in the wider literature on educational field research [2], [10]. Contemporary methodological discourse acknowledges that contextually grounded evidence is frequently more illuminating for pedagogical innovation in complicated educational environments than tight experimental control.

The methodological approach of this study conforms to growing criteria in STEM education research that emphasize contextual relevance, transparency, and practical importance. The methodology offers a comprehensive framework for assessing observation-driven STEM instruction using a descriptive pre–post design, context-sensitive equipment, and accessible analytical tools [22]. Significantly, it provides a reproducible framework for subsequent research aimed at evaluating educational interventions in rural and underfunded school environments.

This study employs a descriptive pre–post design suitable for assessing educational interventions in genuine school-based outreach settings. The approach does not provide causal inference but facilitates the detection of significant learning changes linked to the intervention within real-world limitations.

## Data Collection

The purpose of this study was to assess the effects of an observation-driven, astronomy-based STEM intervention on students' learning experiences through the methodical and ethically sound collecting of data. A pre and post data collecting method was utilized to assess alterations in students' conceptual comprehension, practical abilities, attitudes, and learning clarity before to and following their participation in the program.

Before the intervention was implemented, a structured questionnaire (pre-test) was delivered to participating pupils during regular school hours. The objective of this first data collection was to provide a baseline profile of students' past knowledge, exposure to astronomical ideas, confidence in STEM education, and familiarity with scientific instruments. Explicit instructions were given, and students independently completed the questionnaire under the oversight of educators and researchers to guarantee uniformity and reduce response bias.

Upon concluding the three-session astronomy-focused STEM program, the identical questionnaire (post-test) was re-administered to the students. The post-program data collection occurred immediately following the intervention to document students' reported learning results while the experience was fresh. The utilization of similar instruments for both pre- and post-tests assured response comparability and enhanced the internal consistency of the findings.

The surveys had closed-ended items with categorical response scales, facilitating the acquisition of quantitative data appropriate for frequency and percentage analysis. All responses were gathered anonymously to promote candid reporting and mitigate social desirability bias. Completed surveys were verified for completeness prior to coding and entry into a database for analysis.

The data collecting procedure aimed to harmonize scientific rigor with the practical limitations of a school-based outreach program, ensuring that the data properly represented students' learning experiences in a genuine educational context.

The data analysis for this project is done using quantitative techniques. Descriptive statistics, including means, percentages, and graphical representations, are employed to evaluate the questionnaire findings and demonstrate the initiative's efficacy. This study aimed to examine the impact of astronomical outreach activities on secondary students' interest in STEM fields. The participants received a questionnaire consisting of nine items. The questions aimed to gather statistics on the project's effectiveness. Participants are required to formulate their replies according to the "Likert" scale, as specified in Table 1.

Table 1 Likert scale

Scale	Indicator
5	Strongly Agree
4	Agree
3	Not Sure
2	Disagree
1	Strongly Disagree

Table 1 demonstrates that scale 1 reflects a considerable disagreement about their comprehension of the importance of this project. A score of 2 signifies disagreement with the concept and awareness of the project's importance. A scale of 3 thereafter presents an unclear representation of their viewpoint and understanding of the project's importance. A score of 4 indicates concurrence with their perspective and an understanding of the importance of their undertaking. A rating of 5 signifies a strong alignment between the indicators and the project's evaluation. Participants in two astronomy programs were requested to complete questionnaires to gather quantitative data. Ninety-two surveys were disseminated to evaluate the project's efficacy.

## RESULT AND DISCUSSION

The pre-program data demonstrate that students began the intervention with insufficient preparedness for experiential STEM education, especially in astronomy-related areas. Table 1 indicates that the majority of

students had low to moderate levels (about 70 to 85%) of basic STEM comprehension prior to the program. This distribution indicates that although students had some acquaintance with STEM vocabulary, they lacked the mental clarity necessary to articulate or apply these concepts effectively.

Table 1. Pre-program distribution of students’ STEM understanding

Category	Percentage (%)
Low	45
Moderate	35
Good	15
Very Good	5

Table 1 shows that prior to the intervention, 80% of students were clustered at low to moderate levels of STEM understanding, indicating limited conceptual clarity before exposure to observation-driven learning.

The most inadequate baseline performance was noted in astronomy knowledge and telescope utilization. Table 2 indicates that around 60 to 80% of students indicated inadequate proficiency in various areas, with less than 10% exhibiting significant practical skills. This discovery identifies a distinct pedagogical need and serves as a crucial benchmark for analysing post-intervention results, given that the cohort began with limited prior experience in genuine scientific observation.

Table 2. Pre-program distribution of astronomy knowledge and telescope skills

Category	Percentage (%)
Low	60
Moderate	20
Good	10
Very Good	10

Table 2 indicates that most students had little proficiency in astronomy and telescope operation, corroborating their modest prior experience with actual scientific observation.

Table 3. Post-program distribution of students’ STEM understanding

Category	Percentage (%)
Low	3
Moderate	12
Good	45
Very Good	40

Subsequent to the execution of the observation-driven astronomy program, the post-program outcomes reveal a significant increase across all evaluated areas. Table 3 indicates that around 80 to 90% of pupils attained strong or very good levels of general STEM comprehension, but the poor group decreased to below 5%. This pattern

signifies a comprehensive enhancement across the whole cohort rather than advancements restricted to a limited group of high-performing kids.

The greatest significant enhancement transpired in astronomy-specific areas. Table 4 indicates that following the intervention, around 85 to 95% of pupils attained proficient or exemplary levels in astronomical knowledge and telescope operation. This signifies a substantial reallocation from the pre-program profile depicted in Table 2.

Table 4. Post-program distribution of astronomy knowledge and telescope skills

Category	Percentage (%)
Low	5
Moderate	10
Good	40
Very Good	45

Table 4 illustrates a significant increase in astronomy-related competences, with 85% of students exhibiting high to very strong practical skills post-program.

Figure 1 summarizes the extent of pre–post changes across domains, depicting percentage increases between about +50% and +78%. The most significant improvements are associated with areas exhibiting the lowest initial performance, hence underscoring the intervention's efficacy in mitigating existing learning deficiencies.

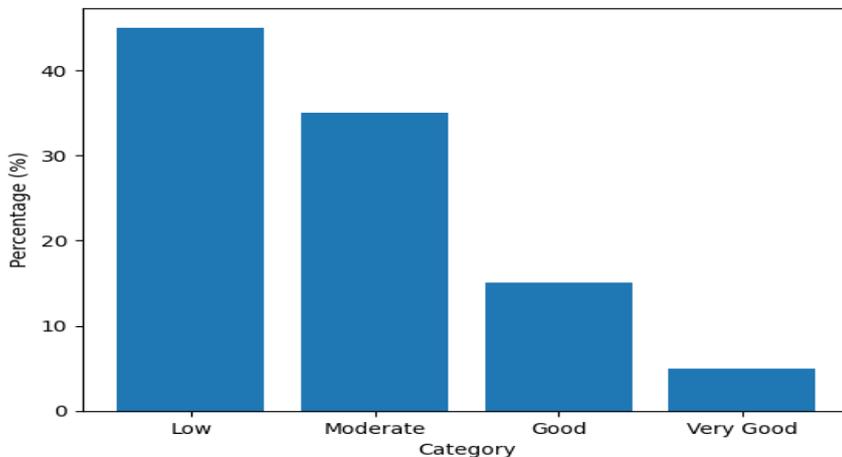


Figure 1. Pre-program STEM Understanding

The learning gains depicted in Figure 1 may be understood using the educational framework of observation-driven learning. The method started training with direct astronomical observation, allowing students to anchor abstract STEM concepts in observable occurrences. This sequencing differs from traditional STEM education, where abstract representations often precede experiential learning.

The shift of results towards higher competency categories in Tables 3 and 4 indicates that students reconstructed conceptual understanding rather than just accumulating factual knowledge. Observation offered a tangible reference, enabling explanations and models to serve as interpretative instruments rather as disjointed data.

The alteration in response distribution presented in Table 3 signifies that students cultivated a more cohesive and integrated comprehension of STEM. The prevalence of replies in the good and very good categories indicates enhanced conceptual clarity and interdisciplinary integration.

Knowledge of astronomy. The ideas of astronomy, typically abstract and spatially challenging, shown significant improvement. Table 4 demonstrates that the post-intervention prevalence of higher proficiency categories indicates a successful conceptual transformation corroborated by direct observation.

Utilization of telescopes and practical competencies. The enhancement of telescope-related abilities is among the most significant results. Figure 2 depicts the significant reduction in low-skill replies alongside the corresponding rise in high-skill responses, signifying that students developed procedural proficiency through organized practical involvement and directed practice.

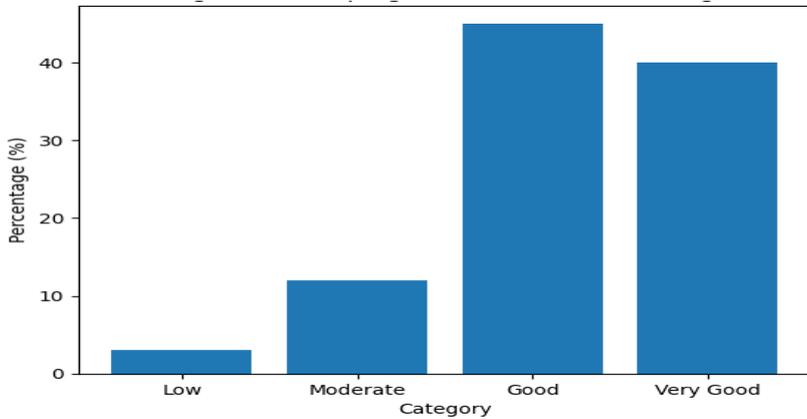


Figure 2. Post-program STEM Understanding

Integrated STEM implementation. The enhanced capacity of students to utilize mathematical and spatial reasoning for interpreting observations is evidenced by the post-program distributions presented in Table 3. This pattern signifies integrated learning instead than discrete skill acquisition.

In addition to numerical improvements, the collective data from Tables 1 until 4 and Figures 1 and 2 indicates a more extensive educational transformation. The steady progression from low/moderate classifications to high/very good classifications across several domains indicates a shift from passive material consumption to active meaning construction.

The observation-driven method seems to have redefined pupils as active participants in scientific inquiry instead of mere receivers of information. This transition is especially important in a rural environment, where possibilities for genuine STEM involvement are often restricted.

The descriptive pre–post design does not allow for causal assertions; yet, the uniformity and extent of change shown in all tables and figures offer compelling practical evidence of the program's efficacy. The correlation between baseline impairments (Tables 1 and 2) and post-intervention improvements (Tables 3 and 4; Figures 1 and 2) enhances the interpretative validity of the results.

The most significant proportionate improvements were noted in areas with the lowest initial performance, suggesting that the intervention targeted authentic learning deficiencies rather than bolstering pre-existing strengths.

**Limitation**

Notwithstanding the favorable results documented, certain limitations of this study must be recognized. The study utilized a descriptive pre–post design lacking a control or comparison group, hence constraining the capacity to infer causal relationships concerning the intervention's efficacy. The observed enhancements should thus be construed as learning gains linked to program participation rather than conclusive proof of causal influence. This design decision illustrates the practical and ethical limitations frequently faced in school-based outreach research; yet, subsequent studies should implement quasi-experimental or experimental methodologies, incorporating matched comparison groups or delayed-intervention cohorts, to enhance causal inference.

Secondly, the research was performed in a singular rural secondary school, perhaps constraining the generalizability of the results to alternative educational settings, such as metropolitan or well-resourced institutions. This context-specific emphasis was deliberate, as rural and under-resourced environments continue to be underrepresented in STEM education studies. Subsequent study should thus undertake multi-site replication across many educational settings to assess the transferability and scalability of observation-based STEM instruction.

The study predominantly utilized self-reported questionnaire data, which may be susceptible to response and social desirability biases. Although self-report instruments are commonly utilized and suitable for assessing outreach-based educational interventions, future research should integrate data triangulation methods, such as classroom observations, performance-based assessments (e.g., telescope operation tasks), and analysis of student learning artifacts, to deliver a more thorough evaluation of learning outcomes.

The current study evaluated outcomes immediately post-intervention and therefore does not reflect long-term retention or enduring impacts on students' STEM learning paths. Longitudinal studies are advised to investigate the durability of conceptual comprehension, sustained participation in STEM activities, and possible effects on course selection and career ambitions. Mitigating these constraints will enhance the evidentiary foundation for observation-driven STEM pedagogy and facilitate its wider implementation across many educational contexts.

This study's findings hold significant implications for teacher professional development (PD), especially for the execution of observation-driven STEM instruction. The significant learning improvements noted in students indicate that successful facilitation of observation-based learning necessitates teachers to transcend mere subject delivery and engage in active inquiry and sense-making facilitation.

Professional development programs should concentrate on equipping educators with the competencies to utilize observation as a pedagogical tool, encompassing the management of scientific instruments like telescopes, the organization of guided observation activities, and the facilitation of student interpretation of empirical evidence. Educators must assurance not just in utilizing equipment but also in assisting students in converting observations into conceptual explanations connected to fundamental STEM principles such as motion, scale, and spatial connections.

Furthermore, professional development activities should prioritize inquiry-oriented discourse tactics, allowing educators to facilitate questioning, rectify misunderstandings identified via observation, and support evidence-based reasoning. Observation-driven learning redefines instructors as facilitators of knowledge instead of just providers of answers, necessitating that professional development aligns with this pedagogical transformation.

The research underscores the significance of university–school collaborations as a means for enduring professional growth. Collaboration with university educators and scientists offers instructors continuous mentorship, access to specialized resources, and exposure to genuine scientific procedures. Such collaborations can facilitate the incorporation of observation-based methodologies into standard classroom practices, guaranteeing that educational innovation transcends temporary measures.

Targeted and practice-oriented professional development is crucial for the expansion and maintenance of observation-driven STEM instruction. Enhancing teachers' pedagogical subject understanding and facilitation abilities may significantly impact the transformation of STEM education into more interactive, inclusive, and meaningful learning experiences through professional development initiatives.

## CONCLUSIONS

This study evaluated the efficacy of an observation-driven learning methodology applied inside an astronomy-focused STEM program in a rural secondary school setting. The results indicate that students began the program with insufficient conceptual understanding and practical expertise in STEM, especially in astronomy-related fields. The baseline results indicated that most students exhibited low to moderate levels of comprehension and proficiency (Tables 1 and 2), underscoring a significant pedagogical deficiency related to

abstract and theory-based STEM training. Post-intervention, significant improvements were noted in all evaluated areas.

Post-program outcomes indicated a significant shift into elevated competency categories, with the majority of students attaining good to very good levels of STEM comprehension and practical skills (Tables 3 and 4; Figures 1 and 2). The extent and uniformity of these increases suggest that the intervention was successful in facilitating substantial learning rather than mere incremental or isolated enhancement.

The most significant improvements were noted in areas with the lowest initial performance, specifically in astronomy knowledge and telescope utilization. This trend indicates that observation-driven learning effectively remedied existing learning deficiencies by anchoring abstract STEM concepts in tangible, observable experiences. By establishing observation as the foundational aspect of learning, students reconstructed their understanding, gained confidence in utilizing scientific instruments, and synthesized concepts across STEM fields.

The descriptive pre–post design does not allow for causal inference; nonetheless, the correlation between initial deficits and subsequent post-intervention improvements offers compelling practical evidence of the efficacy of observation-driven education. The study provides empirical evidence that astronomy-based experiential learning is an effective technique for enhancing STEM teaching in rural and under-resourced secondary schools.

The results indicate that STEM education may be markedly improved by the implementation of observation-based teaching methods. Educators are urged to provide observable phenomena at the outset of the learning process, enabling students to engage and inquire prior to the provision of formal explanations. This technique can diminish cognitive obstacles linked to abstract training and facilitate a more profound conceptual comprehension, especially for students with less prior experience in STEM disciplines.

The findings suggest that astronomy can function as a potent integrative framework for STEM education. Curriculum makers can contemplate integrating organized observation-based activities, such as guided telescope utilization, celestial observation, or spatial reasoning exercises, into current STEM disciplines. Astronomy should be seen not just as an enrichment subject but as a teaching tool for the cohesive integration of scientific, mathematical, and technological concepts.

The successful execution of observation-driven learning necessitates that educators possess confidence in conducting practical activities and directing inquiry-based discussions. Professional development programs should thus encompass instruction in the utilization of scientific instruments, facilitation of observations, and methodologies for correlating observed events with abstract models. University-school collaborations can significantly contribute to enhancing capacity growth.

The research underscores the capacity of observation-based STEM initiatives to mitigate educational disparities in rural settings. Access to genuine scientific experiences, frequently constrained in underfunded schools can be improved by transportable equipment, outreach programs, and partnerships with higher education institutions. These initiatives can mitigate opportunity disparities and promote more inclusivity in STEM involvement.

The study methodologically illustrates the efficacy of descriptive pre–post designs and frequency-based analysis in assessing instructional innovation inside genuine educational environments. Subsequent research might expand upon this study by utilizing longitudinal designs, comparative groups, or mixed-method methods to better investigate the sustainability and transferability of observation-driven STEM instruction in other contexts.

This study's findings endorses observation-driven astronomy learning as an effective and context-sensitive method for improving STEM teaching. By transitioning instruction from theoretical exposition to experiential engagement, educators may cultivate enhanced comprehension, improved abilities, and more significant student involvement in STEM education. This method has significant potential for improving educational fairness and teaching creativity in rural secondary schools.

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