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Rotation-Based Astronomy Learning through a Mobile Science Vehicle: Changes in Students' Celestial Coordinate Conceptual Understanding and Telescope Operation Procedural Knowledge

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Abstract

Students in small and resource-limited schools often have limited access to specialized astronomy equipment and practical learning experiences. This study examined changes in secondary school students' celestial coordinate conceptual understanding and telescope operation procedural knowledge after participation in rotation-based astronomy activities delivered through a university Mobile Science Vehicle. Participants were 105 students in Grades 8–12 from a purposively selected resource-limited school in Surin Province, Thailand. The one-day program comprised three stations: celestial coordinate identification using physical models, simulated sky observation using star charts and a mobile planetarium, and telescope setup and operation. Data were collected using a 10-item Test of Celestial Coordinate Conceptual Understanding (TCCU) and a 10-item Telescope Operation Knowledge Test (TOKT) and analyzed descriptively using percentages of correct responses. Overall TCCU performance increased from 41.77% to 75.60%, a gain of 33.83 percentage points, while TOKT performance increased from 55.52% to 78.00%, a gain of 22.48 percentage points. Item-level results showed that improvement was not uniform; celestial coordinate items 2 and 8 remained particularly difficult, and some telescope operation items showed lower posttest percentages in selected grade levels. The findings indicate higher immediate posttest performance following participation and suggest that the Mobile Science Vehicle can provide a practical mechanism for delivering specialized astronomy resources to resource-limited schools. However, the one-group design, descriptive analysis, and immediate posttest limit causal interpretation.

Keywords: mobile science vehicle; astronomy education; celestial coordinates; mobile planetarium; rotation-based learning; telescope operation

1. Introduction

Astronomy is an important component of science education because it connects knowledge from physics, mathematics, technology, and Earth and space science with natural phenomena that learners can directly observe in the sky. It also provides a meaningful context for promoting students' interest in science, technology, engineering, and mathematics (STEM). Astronomy learning, however, involves more than the memorization of scientific facts (Sarapak, et al., 2025). It requires spatial reasoning, coordination between different frames of reference, and the ability to relate Earth-based observations to models of celestial motion (Cole et al., 2018; Plummer, 2014; Plummer et al., 2014; Salimpour et al., 2021). These cognitive demands contribute to persistent alternative conceptions concerning the positions, motions, and spatial relationships of celestial objects, even among students who have previously studied astronomy in formal science courses (Slater et al., 2018). Celestial coordinate systems are particularly challenging because students must understand the celestial sphere, angular measurements, the observer's position, and the relationships between the horizontal coordinate system, including altitude and azimuth, and the equatorial coordinate system, including right ascension and declination. Consequently, instruction based primarily on verbal explanations and two-dimensional illustrations may be insufficient for developing conceptual understanding that can be applied to authentic astronomical observation (Sarapak, et al., 2025).

Research in astronomy education suggests that learning environments incorporating multiple representations and a progression from concrete models to simulations and practical applications can support students' understanding of abstract spatial concepts. The multiple external representations framework proposes that physical models, diagrams, symbolic systems, maps, and virtual environments can complement one another, constrain inappropriate interpretations, and promote integration across representational forms when they are carefully sequenced and explicitly connected (Ainsworth, 2006). In astronomy education, instructional approaches that connect Earth-based observations with space-based frames of reference have been shown to facilitate more sophisticated explanations of apparent celestial motion (Plummer, 2014; Plummer et al., 2014). Planetariums, including portable planetariums, can provide immersive visual environments in which learners examine the positions and movements of celestial objects without the limitations imposed by weather, observation time, or light pollution. Such environments can therefore function as spatial learning scaffolds that support the visualization of complex astronomical relationships (Everding & Keller, 2020; Türk & Kalkan, 2015). In addition, mobile technologies and augmented-reality applications can connect star charts and digital information with the actual positions of objects in the sky, thereby supporting celestial object identification, observational engagement, and motivation to learn astronomy (Soga et al., 2011; Tian et al., 2014). Nevertheless, the educational effectiveness of these resources depends not merely on the availability of technology, but also on the design of learning activities that enable students to translate and integrate information across physical models, star charts, simulated sky environments, and practical observation activities (Sarapak et al., 2025).

In addition to understanding celestial coordinate systems, observational astronomy requires procedural knowledge of telescope setup and operation. Students need to understand the functions of telescope components and the appropriate procedures for equipment preparation, telescope assembly, alignment, target acquisition, and target tracking. Such procedural knowledge extends beyond the recognition or memorization of equipment names because learners must determine which actions should be performed, in what order, under which conditions, and for what purposes. Research involving online and remotely operated telescopes has demonstrated that engaging students in target selection, observation planning, data collection, and image analysis can improve their understanding

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of telescope operation, astronomical concepts, and scientific inquiry processes (Gould et al., 2007). Similarly, field-based astronomy activities conducted with students in rural educational contexts have supported connections among physics, mathematics, and astronomy, although learners continued to experience difficulties in understanding the celestial sphere, stellar motion, and astronomical models (Pineda et al., 2023). These findings indicate that exposure to observational equipment or simulations as isolated learning experiences may not be sufficient. Conceptual understanding and procedural knowledge should instead be developed in an interconnected manner, allowing students to use their understanding of position and coordinate systems to explain the procedures involved in telescope alignment, target acquisition, and tracking.

Despite the potential of these instructional approaches, access to high-quality astronomy learning experiences remains uneven, particularly in small, rural, and resource-limited schools. Such schools may lack celestial sphere models, planetarium facilities, telescopes, and teachers with specialized astronomy experience. Consequently, students may encounter celestial coordinates and telescope procedures primarily through textbooks, static illustrations, or teacher-centered explanations, with limited opportunities to manipulate three-dimensional models, explore simulated sky environments, or operate astronomical equipment. Mobile science laboratory and outreach programs have been implemented to address similar resource limitations by transporting equipment, instructional materials, and trained facilitators directly to schools. These programs can provide students with access to practical science experiences that individual schools may be unable to establish or maintain independently (Long et al., 2012). Within the context of Surin Province, mobile science activities organized by a university have also demonstrated the feasibility of bringing interactive physics learning experiences to school students and have reported improvements in students' post-activity understanding (Sreejivungsa et al., 2025). However, previous studies have generally examined planetariums, digital simulations, augmented reality, remote telescopes, or mobile laboratories as separate instructional interventions. Limited empirical evidence is available regarding the integration of celestial coordinate models, star charts, a mobile planetarium, and telescope operation into a single rotation-based learning sequence delivered through a Mobile Science Vehicle. Moreover, few studies have simultaneously examined changes in students' conceptual understanding of celestial coordinates and their procedural knowledge of telescope setup and operation in resource-limited educational settings.

To address the identified research gap, this study implemented a rotation-based astronomy learning program through the Mobile Science Vehicle of Surindra Rajabhat University for secondary school students in a resource-limited school. The program integrated three interconnected learning stations involving physical celestial sphere models and coordinate-mapping activities, star charts and simulated sky observation in a mobile planetarium, and telescope setup and operation. The instructional sequence was designed to provide students with opportunities to connect abstract celestial coordinate concepts with visual representations, simulated observations, and practical telescope-related procedures within a short-duration outreach context. Accordingly, the study aimed to: (1) examine changes in students' conceptual understanding of celestial coordinates before and after participating in the Mobile Science Vehicle-based astronomy activities; and (2) examine changes in students' procedural knowledge of telescope setup and operation before and after participating in the activities. The findings are expected to provide empirical information regarding the use of integrated, rotation-based astronomy activities in resource-limited educational settings and may inform the refinement of university science outreach programs, short-duration astronomy learning activities, and future Mobile Science Vehicle-based initiatives for schools with limited access to specialized astronomy facilities.

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2. Methodology

2.1 Research Design

This study employed a quantitative one-group pretest–posttest design to examine changes in students' celestial coordinate conceptual understanding and telescope operation procedural knowledge following their participation in Mobile Science Vehicle-based astronomy activities. The study did not include a control or comparison group. Therefore, differences between the pretest and posttest percentages were interpreted as changes observed following participation in the activities rather than definitive evidence that the activities alone caused the changes.

2.2 Participants and Research Context

The participants were 105 secondary school students in Grades 8–12 who attended a one-day academic outreach program organized through the Mobile Science Vehicle of the Faculty of Science and Technology, Surindra Rajabhat University. The participants were enrolled in a small school in Surin Province, Thailand. The school was selected through purposive sampling because it had requested specialized academic support and had limited access to astronomy equipment, planetarium facilities, and specialized learning resources. The participants were approximately 13–18 years of age. The sample consisted of 10 Grade 8 students, 24 Grade 9 students, 23 Grade 10 students, 11 Grade 11 students, and 37 Grade 12 students, resulting in a total of 105 participants. The participants were divided into small groups and rotated through three astronomy learning stations. The Mobile Science Vehicle transported the instructional resources, astronomy models, mobile planetarium equipment, telescopes, and learning materials to the participating school.



Figure 1. Astronomy learning resources delivered through the Mobile Science Vehicle, including celestial coordinate representations, a physical celestial sphere model, a telescope, and an inflatable mobile planetarium.

2.3 Mobile Science Vehicle-Based Astronomy Activities

The learning intervention was implemented as a one-day academic outreach program through the university's Mobile Science Vehicle. The vehicle served as the principal mechanism for transporting specialized astronomy learning resources, equipment, and facilitators to the participating school. As illustrated in Figure 1, the learning resources delivered through the Mobile Science Vehicle included celestial coordinate representations, a physical celestial sphere model, a telescope, and an inflatable mobile planetarium. These resources were integrated into the three rotation-based activities to help students connect abstract celestial coordinate concepts with visual representations, simulated sky observation, and telescope operation procedures. The program consisted of three interconnected activity stations. Participants were divided into small groups, and each group participated in one station for two hours before rotating to the next station. The rotation continued until all groups had completed the three activities. Therefore, the total

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instructional duration was six hours, excluding orientation, pretest and posttest administration, transitions between stations, breaks, and equipment preparation.

The sequence was designed to guide students progressively from conceptual representations of the celestial sphere to simulated sky observation and telescope-related procedural knowledge. Station 1 focused on celestial coordinate identification, Station 2 involved star-chart activities and simulated sky observation in the mobile planetarium, and Station 3 focused on telescope setup and operation procedures. The structure of the three activities is presented in Table 1.

2.4 Research Instruments

Two instruments were used to collect data and assess the two measured outcomes.

2.4.1 Test of Celestial Coordinate Conceptual Understanding

The Test of Celestial Coordinate Conceptual Understanding, abbreviated as TCCU, consisted of 10 test items. It assessed students' understanding of the celestial sphere, the horizontal coordinate system, altitude and azimuth, the equatorial coordinate system, right ascension and declination, celestial object positions, coordinate interpretation, and apparent celestial motion. The results were reported as percentages of correct responses. Higher percentages indicated a greater proportion of correct responses. A representative sample item from the TCCU assessed students' understanding of the horizontal celestial coordinate system, particularly azimuth. For example, students were asked: "If a star is located exactly in the western direction, what is its azimuth?" The response options were 90°, 180°, 270°, and 360°, with 270° as the correct answer. This item illustrates how the instrument assessed students' ability to apply celestial coordinate concepts to the position of an object in the sky.

Table 1 Structure of the Mobile Science Vehicle-Based Rotation Activities

Station	Activity title	Duration	Learning focus	Activity description
1	Celestial Coordinate Identification	2 hours	Celestial coordinate understanding	Students used physical models of the celestial sphere and coordinate-mapping activities to examine the relationships among altitude, azimuth, right ascension, and declination. They practiced plotting and identifying hypothetical celestial objects in simulated situations.
2	Mobile Planetarium and Star-Chart Activity	2 hours	Application of celestial coordinate concepts	Students used star charts inside an inflatable mobile planetarium to identify constellations, examine celestial object positions, and observe the apparent movement of stars in a simulated night-sky environment.
3	Telescope Setup and Operation	2 hours	Telescope operation procedural knowledge	Students were introduced to telescope components, safe equipment preparation, assembly sequences, alignment procedures, coordinate selection, target acquisition, and target-tracking procedures.

2.4.2 Telescope Operation Knowledge Test

The Telescope Operation Knowledge Test, abbreviated as TOKT, consisted of 10 test items It assessed students' knowledge of telescope components, equipment preparation,

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safe handling, assembly sequences, alignment procedures, coordinate selection, target acquisition, target tracking, and verification of telescope setup. The instrument assessed students' responses to test items rather than their direct performance in operating a telescope. Therefore, it was interpreted as a test of telescope operation procedural knowledge rather than a direct assessment of psychomotor performance. A representative sample item from the TOKT assessed students' knowledge of telescope principles and components. For example, students were asked: "Which of the following represents the most important operating principle of a reflecting telescope?" The response options were: (a) using a convex lens to collect light, (b) using a concave mirror to collect light, (c) using a prism to separate the spectrum of light, and (d) using a filter to filter light. The correct answer was (b), using a concave mirror to collect light. This item illustrates the foundational knowledge required for understanding telescope structure and operation.

2.5 Data Collection

Before participating in the learning activities, all students completed the Test of Celestial Coordinate Conceptual Understanding and the Telescope Operation Knowledge Test as pretests. The participants were then divided into small groups. Each group participated in one activity station for two hours before rotating to the next station until all three stations had been completed. The activities were facilitated by pre-service physics teachers and supervised by university lecturers. The facilitators introduced the learning materials, demonstrated equipment use, supervised the mobile planetarium and telescope activities, and supported students during the assigned tasks. Immediately after all three stations had been completed, the students completed the same assessment instruments as posttests. The percentages of correct responses before and after participation were then compared descriptively.

2.6 Data Analysis

The data were analyzed using descriptive statistics. Percentages of correct responses were reported at the overall, grade, and item levels. Changes in the summary percentages were calculated by subtracting the pre-test percentage from the post-test percentage and were expressed as percentage points. The analysis was limited to descriptive percentages; therefore, the findings were not interpreted as statistically significant.

3. Results

The research findings are presented according to the two measured outcomes: celestial coordinate conceptual understanding and telescope operation procedural knowledge.

3.1 Telescope Operation Knowledge

Table 2 presents the percentages of correct responses on the Telescope Operation Knowledge Test before and after participation in the Mobile Science Vehicle-based astronomy activities.

Table 2 Pretest and Posttest Percentages on the Telescope Operation Knowledge Test

Grade level	Number of items	Pre-test score (%)	Post-test score (%)	Change in percentage points
Grade 8	10	50.00	66.00	+16.00
Grade 9	10	43.33	55.00	+11.67
Grade 10	10	65.22	84.78	+19.56
Grade 11	10	58.18	84.55	+26.37
Grade 12	10	55.56	95.73	+40.17
Overall	10	55.52	78.00	+22.48

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As shown in Table 2, the overall percentage of correct responses increased from 55.52% on the pretest to 78.00% on the posttest. This represented an increase of 22.48 percentage points. The post-test percentage was higher than the pre-test percentage in each grade-level summary. Grade 12 showed the largest descriptive increase, from 55.56% to 95.73%, representing an increase of 40.17 percentage points. Grade 11 increased from 58.18% to 84.55%, while Grade 10 increased from 65.22% to 84.78%. Grade 8 increased from 50.00% to 66.00%. Grade 9 showed the smallest descriptive increase, from 43.33% to 55.00%. These results indicate that students answered a greater proportion of questions concerning telescope setup and operation procedures correctly after participating in the activities. However, because the instrument measured answers to test questions rather than direct performance, the results represent telescope operation procedural knowledge rather than psychomotor proficiency.

As presented in Table 3, the item-level results indicated that post-test percentages were higher for most, but not all, items and grade levels. Grade 10 and Grade 12 showed higher post-test percentages for all 10 items. Grade 11 showed higher or equal post-test percentages for most items, although item 5 decreased from 100.00% to 90.91%. Among Grade 8 students, the post-test percentages increased for most items. The largest increase was found for item 6, which increased from 60.00% to 90.00%. However, item 4 decreased from 60.00% to 40.00%. Grade 9 students showed a mixed response pattern. Higher post-test percentages were observed for items 2, 4, 6, 7, 9, and 10. In contrast, lower post-test percentages were found for item 1, which decreased from 62.50% to 41.67%; item 3, which decreased from 33.33% to 25.00%; item 5, which decreased from 37.50% to 33.33%; and item 8, which decreased from 54.17% to 45.83%. For Grade 10 students, the most substantial increase was found for item 8, which increased from 52.17% to 100.00%. Grade 11 showed substantial increases in items 2, 7, 8, and 9. Grade 12 students showed consistently high post-test percentages, ranging from 89.19% to 100.00%. The results therefore indicate a general increase in telescope operation procedural knowledge, but they do not support the conclusion that every test item improved in every grade level. At the sub-concept level, the TOKT items represented several related aspects of telescope knowledge, including telescope principles and components, equipment preparation and assembly, alignment, target acquisition, and tracking. The item-level findings suggest generally higher posttest performance across several of these procedural-knowledge areas, although the pattern was not uniform across all items or grade levels. Therefore, the results indicate that students' immediate posttest knowledge differed across specific aspects of telescope operation rather than improving uniformly across the entire domain.

Table 3 Item-Level Pretest and Posttest Percentages on the Telescope Operation Knowledge Test

Item	Grade 8 Pre-test	Grade 8 Post-test	Grade 9 Pre-test	Grade 9 Post-test	Grade 10 Pre-test	Grade 10 Post-test	Grade 11 Pre-test	Grade 11 Post-test	Grade 12 Pre-test	Grade 12 Post-test
1	60.00	70.00	62.50	41.67	69.57	91.30	81.82	81.82	54.05	97.30
2	60.00	70.00	41.67	75.00	65.22	73.91	63.64	100.00	62.16	89.19
3	70.00	80.00	33.33	25.00	43.48	52.17	45.45	72.73	51.35	94.59
4	60.00	40.00	54.17	66.67	69.57	91.30	63.64	72.73	48.65	94.59
5	60.00	70.00	37.50	33.33	69.57	95.65	100.00	90.91	83.78	100.00
6	60.00	90.00	37.50	41.67	73.91	86.96	63.64	90.91	56.76	91.89
7	30.00	50.00	25.00	41.67	47.83	56.52	18.18	72.73	43.24	94.59
8	30.00	50.00	54.17	45.83	52.17	100.00	27.27	72.73	37.84	94.59
9	50.00	70.00	33.33	45.83	73.91	86.96	54.55	100.00	54.05	97.30
10	50.00	70.00	50.00	62.50	86.96	95.65	100.00	100.00	83.78	100.00

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3.2 Celestial Coordinate Conceptual Understanding

Table 4 presents the percentages of correct responses on the Test of Celestial Coordinate Conceptual Understanding before and after participation in the activities.

Table 4 Pretest and Posttest Percentages on the Test of Celestial Coordinate Conceptual Understanding by Grade Level

Grade level	Number of items	Pre-test score (%)	Post-test score (%)	Change in percentage points
Grade 8	10	32.00	71.00	+39.00
Grade 9	10	43.33	66.67	+23.34
Grade 10	10	33.04	77.83	+44.79
Grade 11	10	64.55	82.73	+18.18
Grade 12	10	34.32	80.81	+46.49
Overall	10	41.77	75.60	+33.83

As shown in Table 4, the overall percentage of correct responses increased from 41.77% on the pretest to 75.60% on the posttest. This represented an increase of 33.83 percentage points. The post-test percentage was higher than the pre-test percentage in each grade-level summary. Grade 12 showed the largest descriptive increase, from 34.32% to 80.81%, representing an increase of 46.49 percentage points. Grade 10 increased from 33.04% to 77.83%, while Grade 8 increased from 32.00% to 71.00%. Grade 9 increased from 43.33% to 66.67%. Grade 11 had the highest reported pre-test percentage and showed the smallest descriptive increase, from 64.55% to 82.73%. These results suggest that students answered a greater proportion of questions concerning celestial coordinate concepts correctly after participating in the activities.

Table 5 Item-Level Pretest and Posttest Percentages on the Test of Celestial Coordinate Conceptual Understanding

Item	Grade 8 Pre-test	Grade 8 Post-test	Grade 9 Pre-test	Grade 9 Post-test	Grade 10 Pre-test	Grade 10 Post-test	Grade 11 Pre-test	Grade 11 Post-test	Grade 12 Pre-test	Grade 12 Post-test
1	100.00	90.00	70.83	70.83	86.96	100.00	90.91	100.00	78.38	89.19
2	0.00	0.00	20.83	4.17	4.35	0.00	36.36	9.09	18.92	10.81
3	10.00	80.00	25.00	91.67	0.00	52.17	0.00	54.55	18.92	72.97
4	50.00	80.00	45.83	87.50	47.83	86.96	63.64	90.91	27.03	86.49
5	30.00	90.00	45.83	95.83	26.09	95.65	81.82	90.91	45.95	91.89
6	50.00	100.00	58.33	95.83	73.91	95.65	81.82	100.00	40.54	86.49
7	40.00	80.00	41.67	79.17	21.74	91.30	36.36	100.00	16.22	78.38
8	10.00	0.00	20.83	8.33	4.35	0.00	0.00	0.00	5.41	2.70
9	30.00	100.00	58.33	79.17	34.78	100.00	72.73	100.00	29.73	89.19
10	0.00	90.00	29.17	41.67	21.74	95.65	100.00	100.00	21.62	94.59

The item-level results showed clear increases for many items related to the application of celestial coordinate concepts. Items 3–7, 9, and 10 generally showed higher post-test percentages across the grade levels. For Grade 8 students, the largest increases were observed for items 9 and 10. Item 9 increased from 30.00% to 100.00%, while item 10 increased from 0.00% to 90.00%. Items 3, 5, and 6 also showed substantial increases. However, item 1 decreased from 100.00% to 90.00%, item 2 remained at 0.00%, and item 8 decreased from 10.00% to 0.00%. For Grade 9 students, items 3, 4, 5, 6, and 7 showed substantial increases. Item 3 increased from 25.00% to 91.67%, and item 5 increased from 45.83% to 95.83%. Item 1 remained unchanged at 70.83%. In contrast, item 2 decreased from 20.83% to 4.17%, and item 8 decreased from 20.83% to 8.33%. Grade 10 students showed substantial increases for items 3–7, 9, and 10. Items 9 and 10 reached post-test percentages of 100.00% and 95.65%, respectively. Nevertheless, item 2 decreased from 4.35% to 0.00%, while item 8 decreased from 4.35% to 0.00%. Grade 11 students showed

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higher post-test percentages for items 1, 3–7, and 9. Items 6, 7, and 9 reached 100.00%. Item 10 remained unchanged at 100.00%. However, item 2 decreased from 36.36% to 9.09%, and item 8 remained at 0.00%. Grade 12 students showed substantial increases for items 3–7, 9, and 10. Item 10 increased from 21.62% to 94.59%, and item 5 increased from 45.95% to 91.89%. In contrast, item 2 decreased from 18.92% to 10.81%, and item 8 decreased from 5.41% to 2.70%. The findings indicate that students generally showed higher posttest percentages on several items assessing celestial coordinate concepts. However, items 2 and 8 remained particularly difficult across the grade levels. The low posttest percentages for items 2 and 8 should be interpreted cautiously. The answer keys, item wording, distractors, and alignment between these items and the learning activities should be examined before conclusions are drawn about students' conceptual understanding. At the sub-concept level, the TCCU items represented several aspects of celestial coordinate understanding, including the celestial sphere, horizontal coordinates (altitude and azimuth), equatorial coordinates (right ascension and declination), coordinate interpretation, and apparent celestial motion. The item-level findings indicate that students generally demonstrated higher immediate posttest performance across several of these conceptual areas; however, performance was not uniform. In particular, the consistently low posttest percentages for Items 2 and 8 suggest that the specific coordinate concepts represented by these items remained difficult and may require further instructional emphasis.

3.3 Overall Synthesis of the Results

The findings from the two assessment instruments showed higher overall immediate posttest percentages following participation in the Mobile Science Vehicle-based astronomy activities. For celestial coordinate conceptual understanding, the overall percentage increased from 41.77% to 75.60%, representing an increase of 33.83 percentage points. For telescope operation procedural knowledge, the overall percentage increased from 55.52% to 78.00%, representing an increase of 22.48 percentage points. At the item level, higher posttest percentages were observed for many items in both assessments; however, improvement was not uniform. Celestial coordinate items 2 and 8 remained persistently difficult across most grade levels, while selected telescope operation items showed lower posttest percentages in some grade levels, particularly Grade 9. The results therefore indicate higher overall immediate posttest percentages but do not support the claim that all items, concepts, or procedures improved.

4. Discussion

The present study examined changes in students' conceptual understanding of celestial coordinates and procedural knowledge of telescope setup and operation after participation in rotation-based astronomy activities delivered through a university Mobile Science Vehicle. The percentages of correct responses increased from 41.77% to 75.60% for celestial coordinate conceptual understanding and from 55.52% to 78.00% for telescope operation procedural knowledge. These descriptive findings indicate higher immediate post-activity performance in both domains. However, because the study used a one-group pretest–posttest design without a comparison group or inferential analysis, the results should be interpreted as changes observed following participation rather than as definitive causal effects of the activities.

The higher posttest percentage for celestial coordinate conceptual understanding may be related to the coordinated use of multiple representations. Students progressed from three-dimensional celestial sphere models to two-dimensional star charts and an immersive mobile planetarium. Such a sequence may have helped them connect abstract coordinate concepts with observable positions in the simulated sky. Multiple representations can support learning by presenting complementary information and

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helping learners integrate complex spatial relationships (Ainsworth, 2006). This is particularly relevant in astronomy, where students must coordinate different perspectives, reference frames, and spatial representations (Cole et al., 2018; Plummer, 2014). Previous studies have also shown that classroom and planetarium experiences can support understanding of celestial motion and three-dimensional astronomical relationships (Plummer et al., 2014; Türk & Kalkan, 2015). The higher posttest percentage for telescope operation procedural knowledge may be related to the structured demonstrations and guided activities at the telescope station. Students learned about telescope components, equipment preparation, assembly sequences, alignment procedures, coordinate selection, target acquisition, and target tracking. Presenting these procedures as an organized sequence may have supported students' understanding of both the functions of the equipment and the order of operation. Telescope-based and field-based astronomy activities have similarly been reported to support understanding of astronomical instruments, observation, and scientific inquiry (Gould et al., 2007; Pineda Caro et al., 2023). Nevertheless, the present assessment measured written procedural knowledge rather than students' actual ability to operate a telescope. The findings should therefore not be interpreted as evidence of psychomotor proficiency.

The item-level results showed that improvement was not consistent across all questions. Celestial coordinate items 2 and 8 did not demonstrate the expected gains, while some telescope items remained difficult for Grade 9 students. These patterns may reflect ambiguous wording, insufficient alignment with the activities, high cognitive demand, or differences in students' prior mathematical and spatial knowledge. The larger descriptive gains observed among Grade 12 students may also be related to their greater experience with physics, mathematics, and scientific representations. However, because prior knowledge was not independently measured and no inferential comparisons were conducted, differences between grade levels should be interpreted cautiously. Viewed by sub-concept, the findings also suggest that learning was not uniform across the different components assessed by the two instruments. For celestial coordinate understanding, students appeared to perform better after the activities on several aspects involving coordinate interpretation and application, whereas the concepts represented by Items 2 and 8 remained difficult. For telescope operation knowledge, the item-level patterns similarly suggest variation across knowledge of telescope principles and components, preparation, alignment, target acquisition, and tracking. These findings highlight the value of considering specific conceptual and procedural components in addition to overall test performance.

A practical feature of the study is the use of the Mobile Science Vehicle as an integrated astronomy learning environment. The program combined physical models, star charts, a mobile planetarium, telescopes, and trained facilitators within a single rotation-based sequence. Mobile science programs can expand access to practical science learning in schools that lack specialized equipment and facilities (Long et al., 2012). Similar university-based mobile science activities in Surin Province have also demonstrated the feasibility of delivering interactive science experiences to school students (Sreejivungsa et al., 2025). Although educational equity was not directly assessed, the present model offers a practical approach for providing specialized astronomy learning experiences in resource-limited schools.

Several limitations should be acknowledged. The absence of a control group limits causal interpretation, and the immediate posttest administration assessed only short-term performance rather than retention. The use of descriptive percentages without statistical significance testing also limits the strength of the conclusions. In addition, the sample was drawn from one school, detailed evidence concerning the validity and reliability of the assessment instruments was not reported, and repeated exposure to the same test items

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may have produced testing effects. Most importantly, the telescope assessment measured procedural knowledge rather than actual performance.

Future studies should include comparison groups, larger samples, delayed posttests, inferential statistics, and validated assessment instruments. Performance-based rubrics should also be developed to assess students' ability to assemble, align, focus, and operate telescopes under authentic conditions. Problematic assessment items, particularly celestial coordinate items 2 and 8, should be revised through expert review, cognitive interviews, pilot testing, and item analysis. Overall, the findings provide preliminary descriptive evidence that participation in rotation-based astronomy learning through a Mobile Science Vehicle was associated with higher immediate posttest performance in celestial coordinate conceptual understanding and telescope operation procedural knowledge. Further research is required to establish long-term and practical learning outcomes.

5. Conclusion

This study designed and implemented rotation-based astronomy learning activities delivered through a university Mobile Science Vehicle. The program integrated physical celestial sphere model, star charts, a mobile planetarium, and telescope setup and operation activities for secondary school students in a resource-limited school. The overall percentage of correct responses on the celestial coordinate understanding test increased from 41.77% before the activities to 75.60% after the activities. The overall percentage of correct responses on the telescope operation knowledge test increased from 55.52% to 78.00%. The item-level results indicated higher posttest percentages for many items across both assessment instruments. However, improvement was not observed for every item. Celestial coordinate items 2 and 8 remained particularly difficult, and selected telescope operation items showed lower post-test percentages in some grade levels. The findings suggest that participation in the Mobile Science Vehicle-based rotation activities was associated with higher immediate posttest performance in celestial coordinate conceptual understanding and telescope operation procedural knowledge. The Mobile Science Vehicle also provided a practical mechanism for transporting specialized astronomy resources, equipment, and facilitators to a school with limited access to such learning opportunities. Nevertheless, the study did not include a comparison group, inferential statistical analysis, a delayed post-test, or a direct psychomotor performance assessment. Therefore, the findings should not be interpreted as definitive evidence that the activities caused the observed changes or that students independently mastered telescope operation. The Mobile Science Vehicle-based activity model may provide a useful foundation for astronomy outreach programs in schools with limited resources. Future studies should strengthen the research design, validate assessment instruments, review problematic test items, examine long-term retention, and include direct assessments of telescope operation performance.

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Declaration

The authors declare that Generative AI (ChatGPT/Gemini) was only used to help improve the English language and for minor translation tasks. The AI was not used to create any scientific content, conduct data analysis, or interpret results. All ideas, experimental design, data collection, analysis, and conclusions were solely carried out by

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the authors. Following ethical research standards and academic integrity policies, the authors confirm that AI tools were used openly, ethically, and under the full supervision of the authors to ensure the manuscript's accuracy and appropriateness.

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