

Development and Evaluation of Technology-Supported Astronomy Learning Activities on Celestial Coordinate Systems and Telescope Observation for Pre-Service Physics Teachers

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Abstract

Astronomy learning involves abstract concepts, particularly celestial coordinate systems, the apparent motion of celestial objects, and telescope operation, which can be difficult for pre-service physics teachers to connect with actual observations. This study aimed to develop STEM-based astronomy learning activities, evaluate their quality and appropriateness, and examine participants' conceptual understanding and perceptions after participation. A developmental research approach based on the ADDIE model and a pre-experimental one-group pretest–posttest design was employed with 30 pre-service physics teachers from Years 1–3. The developed package comprised three activities: Celestial Object Identification, Analysis of Coordinate Changes, and Telescope Setup and Observation. Research instruments included the learning activity package, an expert evaluation form, a 30-item conceptual understanding test, and a learner opinion questionnaire. Three experts evaluated the activities before implementation over three weeks (12 instructional hours). Data were analyzed using mean, standard deviation, paired-samples t-test, and item-level analysis. The activities received a very high expert evaluation ($M=4.65$, $SD=0.35$). Mean conceptual understanding scores increased from 11.10 ($SD=4.12$) to 23.50 ($SD=2.46$), with significantly higher posttest scores at the .05 level. Participants also reported very positive perceptions ($M=4.72$, $SD=0.43$). The findings suggest that the developed activities have potential to connect abstract astronomical concepts with physical models, astronomy software, data analysis, and telescope observation.

Keywords: Astronomy education, Celestial coordinate systems, Telescope observation, STEM-based learning, Conceptual understanding, Pre-service physics teachers

1. Introduction

STEM Education has emerged as a significant paradigm in 21st-century educational reform, emphasizing the integration of science, technology, engineering, and mathematics. This approach aims to equip learners with the essential competencies required for a new world driven by innovation (Aggarwal et al., 2023). In this context, Astronomy Education assumes a crucial role as an effective platform for STEM integration, as it is a discipline that inherently merges complex physical and mathematical principles with the observation of real natural phenomena (Fajriani & Masturi, 2023). However, the instruction of astronomy, particularly concerning highly abstract topics such as Celestial Coordinate Systems and practical telescope observation, remains a significant challenge. The quality of this instruction is critically dependent on the preparedness and competency of the educators themselves (Sarapak et al., 2025a). Therefore, preparing pre-service physics teachers—who will serve as the primary personnel driving secondary-level science education—with both deep conceptual understanding and proficient practical skills is a strategic priority of utmost importance for elevating the nation's science education (Sarapak et al., 2025b; Sreejivungsa et al., 2025).

Recent research indicates continuous efforts over the past decade to apply digital technologies in support of astronomy learning. Numerous studies have demonstrated the effectiveness of planetarium software, such as Stellarium and Sky Map, in promoting conceptual understanding and developing learners' digital literacy (Fajriani & Masturi, 2023; Maulana & Masturi, 2023). Furthermore, Virtual Reality (VR) and Augmented Reality (AR) technologies have shown increasingly significant roles in creating immersive learning environments and stimulating student engagement (Aggarwal et al., 2023; Chiang et al., 2019). Concurrently, another body of research has affirmed the irreplaceable value of hands-on experience through the use of actual telescopes, both via direct observation and through remote and robotic telescopes, which serve as vital mechanisms for enhancing practical skills and fostering learning motivation (Kolb et al., 2018; Slater, 2018).

Despite these advancements, the literature still indicates several significant research gaps. First, notwithstanding the widespread application of digital tools, pre-service teachers continue to exhibit deep-rooted misconceptions regarding spatial astronomical concepts (Ozkan & Akcay, 2016; Türk et al., 2015). This suggests that the mere use of technology may not be the sole factor leading to learning success (Sarapak et al., 2025c). Second, current research tends to focus on developing competencies in a single dimension, such as emphasizing software for conceptual understanding or telescopes for practical skills (Lugo López et al., 2022). Consequently, there remains a need for integrated learning activities that connect conceptual understanding with digital tools, physical models, data analysis, and practical telescope observation.

Accordingly, this study aimed to (1) design and develop STEM-based astronomy learning activities on celestial coordinate systems and telescope observation for pre-service physics teachers; (2) evaluate the quality and appropriateness of the developed activities through expert review; and (3) compare pre-service physics teachers' conceptual understanding before and after participating in the developed activities and examine their perceptions of the activities. The findings of this study were expected to provide a systematically developed set of STEM-based astronomy learning activities, together with preliminary evidence of changes in conceptual understanding and participants' perceptions following participation in the activities.

2. Methodology

2.1 Research Design

This study employed a developmental research design guided by the ADDIE instructional design model and a pre-experimental one-group pretest–posttest design. The developmental process was organized into three main stages corresponding to the research objectives.

Stage 1: Analysis, Design, and Development. The researchers analyzed the physics teacher education curriculum, relevant astronomy content, learning objectives, and common misconceptions related to celestial coordinate systems, the apparent motion of celestial objects, and telescope operation. Based on the analysis, three STEM-based learning activities were designed by integrating scientific inquiry, conceptual modeling, digital technology, the engineering design process, and mathematical analysis.

Stage 2: Expert Validation and Revision. The developed activities, student worksheets, teacher guide, learning media, and research instruments were submitted to three experts for content validation and quality evaluation. The materials were revised according to the experts' ratings and qualitative recommendations.

Stage 3: Implementation and Outcome Evaluation. The revised learning activities were implemented with the main study participants using a one-group pretest–posttest design. Astronomy conceptual understanding was assessed before and after the implementation, while participants' perceptions of the activities were examined after completion of the activities.

2.2 Participants

The participants were 30 pre-service physics teachers enrolled in Years 1–3 in the Physics Education Program, Faculty of Science and Technology, Surindra Rajabhat University, during the 2025 academic year. The participants comprised 12 first-year students, 7 second-year students, and 11 third-year students. The participants were selected through convenience sampling based on their enrollment in the Physics Education Program, availability, and willingness to participate in all stages of data collection. All participants received the same learning activities, instructional time, learning materials, testing conditions, and scoring criteria. Participation was voluntary, and the collected data were reported anonymously.

2.3 Development of the STEM-Based Astronomy Learning Activities

The learning activity package was developed to connect abstract astronomical concepts with conceptual representations, hands-on models, digital technology, and authentic telescope observation. The package consisted of three sequential activities.

Activity 1: Celestial Object Identification. This activity introduced the celestial sphere and the identification of celestial objects using horizontal and equatorial coordinate systems. Participants used celestial coordinate diagrams, star charts, and astronomy software to identify and describe the positions of selected celestial objects.

Activity 2: Analysis of Coordinate Changes. Participants investigated how altitude and azimuth coordinates change according to observation time and observer location. They analyzed data, constructed representations, and used evidence to explain the apparent motion of celestial objects in relation to Earth's rotation.

Activity 3: Telescope Setup and Observation. Participants practiced assembling, aligning, and operating a telescope for astronomical observation. They applied celestial coordinate information, selected appropriate eyepieces, recorded observational data, and evaluated the accuracy and limitations of their observations.

Each activity included learning objectives, a problem or observational task, prior-knowledge elicitation, inquiry and data collection, STEM integration, application or

design tasks, reflection questions, student worksheets, and assessment criteria. The developed activity package integrated conceptual representations, hands-on models, and authentic telescope observation. As illustrated in Figure 1, the learning materials included a celestial coordinate diagram, a physical celestial sphere model, and a telescope setup for practical astronomical observation. These components were designed to help pre-service physics teachers connect abstract astronomical concepts with concrete models and real-world observational experiences.

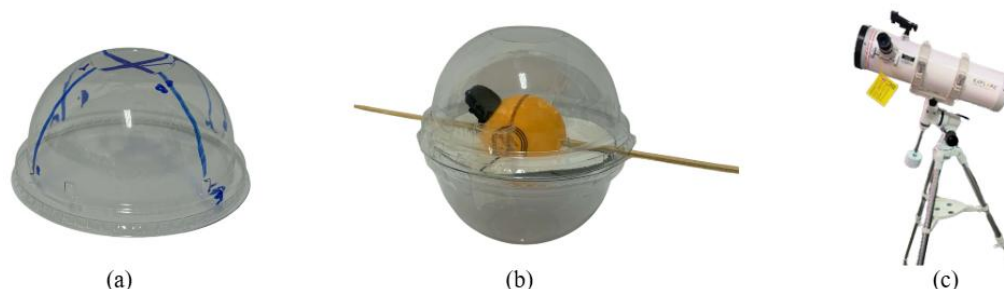


Figure 1. Examples of the developed STEM-based astronomy learning activities: (a) a celestial coordinate representation, (b) a hands-on celestial sphere model, and (c) a telescope setup for astronomical observation.

2.4 Expert Validation

The activities and research instruments were reviewed by three experts for alignment with the intended objectives, quality, and appropriateness. The materials were revised according to the experts' recommendations before implementation.

2.5 Research Instruments

The research instruments consisted of the STEM-based astronomy learning activity package, an expert evaluation form, an astronomy conceptual understanding test, and a learner opinion questionnaire. The activity package comprised three activities: Celestial Object Identification, Analysis of Coordinate Changes, and Telescope Setup and Observation. The activities were supported by student worksheets, a teacher guide, celestial coordinate models, astronomy software, and telescope observation materials.

The developed activities were evaluated by three experts using a five-point rating-scale form covering content, learning process, and practical feasibility. The alignment of the activities and research instruments with the intended objectives was also examined using the Index of Item–Objective Congruence. The astronomy conceptual understanding test consisted of 30 four-option multiple-choice items covering celestial coordinate systems, the apparent motion of celestial objects, coordinate changes, telescope setup, and telescope observation. The learner opinion questionnaire employed a five-point rating scale covering interest in the activities, perceived understanding of celestial coordinates and telescope use, STEM integration, and potential application in future teaching. All activities and research instruments were reviewed and revised according to the experts' recommendations before implementation with the main participants. No separate pilot study was conducted prior to data collection.

2.6 Implementation Procedure

The revised learning activities were implemented with 30 pre-service physics teachers over three weeks for a total of 12 instructional hours. The participants completed the three activities sequentially: Celestial Object Identification, Analysis of Coordinate Changes, and Telescope Setup and Observation. The conceptual understanding test was

administered before and after the activities, while the learner perception questionnaire was administered after completion of all activities.

2.7 Data Analysis

Data were analyzed according to the three research objectives. For the first objective, the structure, components, learning processes, instructional media, and assessment methods of the developed activities were described using descriptive analysis. For the second objective, the quality and appropriateness ratings provided by the three experts were analyzed using mean and standard deviation. For the third objective, pretest and posttest conceptual understanding scores were analyzed using mean and standard deviation, and a paired-samples t-test was used to determine whether the posttest scores were significantly higher than the pretest scores. Item-level percentages of correct responses were also examined. Learner perception questionnaire data were analyzed using mean and standard deviation.

3. Results and discussions

The research findings are presented in four sections: (1) the design and development of the STEM-based astronomy learning activity package, (2) expert evaluation of the quality and appropriateness of the activities, (3) comparison of participants' conceptual understanding before and after the activities, and (4) participants' perceptions of the developed activities.

3.1 Results of the Design and Development of the STEM-Based Astronomy Learning Activity Package

The STEM-based astronomy learning activity package was developed using the ADDIE instructional design model. During the analysis phase, the researchers examined astronomy content, learning objectives, and difficulties commonly associated with celestial coordinate systems and telescope observation. These topics involve abstract reference frames, the apparent motion of celestial objects, and the relationship between geometric coordinate representations and actual observations. Therefore, the activities were designed to connect abstract concepts with physical models, digital technology, data analysis, and practical telescope observation.

Table 1. Structure of the developed STEM-based astronomy learning activity package

No.	Activity	Main objective	STEM integration	Main learning task
1	Celestial Object Identification	To identify celestial objects and their coordinate positions	Science, Technology, and Mathematics	Using celestial coordinate diagrams, star charts, and astronomy software
2	Analysis of Coordinate Changes	To analyze changes in celestial coordinates over time and location	Science, Technology, and Mathematics	Analyzing coordinate data and relating the changes to Earth's rotation
3	Telescope Setup and Observation	To set up and operate a telescope for astronomical observation	Science, Technology, Engineering, and Mathematics	Aligning the telescope, selecting eyepieces, and observing celestial objects

The developed package consisted of three sequential activities. The first activity, Celestial Object Identification, introduced the positions and coordinates of celestial

objects using celestial coordinate diagrams, star charts, and astronomy software. The second activity, Analysis of Coordinate Changes, required participants to examine changes in celestial coordinates according to observation time and observer location and to relate these changes to Earth's rotation. The third activity, Telescope Setup and Observation, provided practical experience in telescope setup, alignment, eyepiece selection, and astronomical observation.

The activities followed a logical sequence from identifying celestial positions to analyzing coordinate changes and applying the concepts during telescope observation. The integration of relevant STEM components within the developed activity package is summarized in Table 1.

As shown in Table 1, the three activities were designed as an interconnected learning sequence in which the main objective, STEM components, and learning tasks progressively supported the application of astronomical concepts. The first activity focused on identifying celestial objects and their coordinate positions by integrating scientific concepts with coordinate representations, and mathematical interpretation. The second activity extended this understanding by requiring participants to analyze changes in celestial coordinates over time and location and relate these patterns to Earth's rotation. The third activity provided an opportunity to apply the knowledge developed in the preceding activities through telescope setup and astronomical observation. In this activity, science and mathematics were combined with technology and engineering practices through telescope alignment, eyepiece selection, and observational decision making. Thus, the three activities progressed from conceptual identification and data analysis to practical application, providing a coherent connection among the learning objectives, STEM integration, and learning tasks.

3.2 Results of the Expert Evaluation

The developed learning activity package was evaluated by three experts in the areas of content, learning process, and practical feasibility. As presented in Table 2, the overall quality and appropriateness of the activity package were rated at a very high level, with a mean score of 4.65 and a standard deviation of 0.35.

Among the evaluated domains, the learning process received the highest rating, with a mean score of 4.70 and a standard deviation of 0.26. The content domain received a mean score of 4.67 and a standard deviation of 0.33, while practical feasibility received a mean score of 4.57 and a standard deviation of 0.45. The relatively small standard deviations indicated limited variation among the experts' ratings. The results showed that the developed activities were appropriate in terms of content, learning process, and practical feasibility. The activities and research instruments were revised according to the experts' recommendations before being implemented with the study participants.

Table 2. Expert evaluation results for the developed learning activities

Assessed domain	Mean	SD	Quality level
Content	4.67	0.33	Very High
Learning Process	4.70	0.26	Very High
Practical Feasibility	4.57	0.45	Very High
Overall	4.65	0.35	Very High

The pattern of expert ratings provides additional information regarding the overall evaluation of the developed activities. The learning process received the highest mean rating ($M = 4.70$, $SD = 0.26$), indicating strong agreement among the experts regarding the organization and appropriateness of the instructional sequence. The content domain was also rated very highly ($M = 4.67$, $SD = 0.33$), supporting the alignment of the astronomy content with the intended learning objectives. Although practical feasibility

received a slightly lower mean rating ($M = 4.57$, $SD = 0.45$), it remained within the very high level. Taken together, the ratings indicate that the experts considered the activities appropriate across content, learning process, and practical implementation. The materials were subsequently revised in accordance with the experts' recommendations before implementation with the participants.

3.3 Comparison of Pretest and Posttest Conceptual Understanding Scores

The comparison of the pretest and posttest scores showed that the participants' astronomy conceptual understanding improved after participating in the developed learning activities. As presented in Table 3, the mean pretest score was 11.10 out of 30 points, with a standard deviation of 4.12, whereas the mean posttest score was 23.50, with a standard deviation of 2.46. The mean score therefore increased by 12.40 points.

The paired-samples t-test showed that the posttest scores were significantly higher than the pretest scores at the .05 level. These findings indicated that the participants demonstrated higher conceptual understanding after completing the activities. The increase may be associated with the sequence of learning experiences that connected celestial coordinate representations, physical models, astronomy software, coordinate-data analysis, and practical telescope observation.

Table 3. Comparison of pretest and posttest conceptual understanding scores

Statistic	Pretest	Posttest	Mean difference
Mean	11.10	23.50	12.40
Standard deviation	4.12	2.46	—

The increase in the mean score from 11.10 to 23.50 indicates that the participants demonstrated greater understanding of the astronomy concepts assessed after completing the activities. In particular, the conceptual understanding test addressed both celestial coordinate systems and practical concepts associated with telescope observation. The improvement therefore reflects increased ability to interpret celestial positions and coordinate changes as well as to apply relevant concepts to telescope setup and observation. However, the total scores alone do not identify which specific concepts changed most substantially. Therefore, an item-level analysis was conducted to examine the patterns of improvement across individual concepts, as presented in the following section.

3.3.1 Item-Level Analysis

The item-level analysis provided additional information regarding the astronomy concepts in which the participants' responses improved. Most test items showed higher percentages of correct responses on the posttest than on the pretest. The largest improvements were observed in items related to celestial coordinate systems, changes in celestial positions, telescope operation, and eyepiece selection.

For example, the percentage of correct responses for Item 14 increased from 10% on the pretest to 90% on the posttest. This item assessed the selection of an eyepiece with a longer focal length for obtaining a wider field of view when locating celestial objects. Similarly, the percentage of correct responses for Item 29 increased from 20% to 90%. This item assessed the selection of a shorter focal length eyepiece to obtain higher magnification when observing details on the lunar surface. These results suggest that participants developed a better understanding of the relationship between eyepiece focal length, magnification, field of view, and the purpose of astronomical observation.

Overall, the pretest–posttest comparison and item-level analysis showed improvements in the participants' understanding of celestial coordinate systems and telescope observation. The use of physical models, astronomy software, and hands-on telescope activities may have provided opportunities for participants to relate abstract

astronomical concepts to actual observational procedures. However, because the study employed a one-group pretest–posttest design without a comparison group, the findings should be interpreted as improvements observed after participation rather than definitive evidence that the activities were the sole cause of the changes.

Table 4: Item-level percentages of correct responses on the pretest and posttest (N = 30)

Item	% Pre-test	% Post-test	$\Delta\%$ (Change)
1	70	90	20
2	40	80	40
3	60	80	20
4	80	80	0
5	50	70	20
6	30	70	40
7	30	70	40
8	40	90	50
9	50	80	30
9	50	80	30
10	20	50	30
11	40	90	50
12	20	70	50
13	30	70	40
14	10	90	80
15	50	60	10
16	30	90	60
17	10	50	40
18	30	80	50
19	20	50	30
20	30	60	30
21	60	100	40
22	10	70	60
23	60	100	40
24	40	80	40
25	30	80	50
26	0	60	60
27	50	80	30
28	40	80	40
29	20	90	70
30	50	90	40

Example items that demonstrate clear conceptual development include:

Item 14: "To see a wider field of view to find objects more easily, what type of eyepiece should be used?" The correct answer is "a. High focal length (e.g., 25 mm)." Eyepieces with high focal length provide a wider field of view and lower magnification, suitable for broad-area searching. The percentage of correct responses for Item 14 increased from 10% on the pretest to 90% on the posttest, representing an increase of 80 percentage points.

Item 29: "If you want to observe the surface details of the Moon, which eyepiece should you choose?" The correct answer is "b. Low focal length eyepiece (high magnification)," which aligns with the principle of increasing magnification to inspect specific details. The percentage of correct responses for Item 29 increased from 20% on the pretest to 90% on the posttest, representing an increase of 70 percentage points.

3.3.2 Discussion of Changes in Conceptual Understanding

The improvement in the participants' posttest scores suggests that their understanding of celestial coordinate systems and telescope observation developed after participating in the STEM-based astronomy learning activities. The activity sequence allowed the participants to progress from identifying celestial objects and coordinate positions to analyzing coordinate changes and applying their understanding during telescope setup and observation. The item-level results showed noticeable improvements in concepts related to telescope operation and eyepiece selection. For example, the percentage of correct responses for Item 14 increased from 10% to 90%, indicating that more participants understood that an eyepiece with a longer focal length provides lower magnification and a wider field of view, making it suitable for locating celestial objects. Similarly, the percentage of correct responses for Item 29 increased from 20% to 90%, suggesting improved understanding of the use of a shorter focal length eyepiece for obtaining higher magnification when observing details of the Moon. These improvements may be associated with the combination of conceptual representations, astronomy software, physical models, and hands-on telescope observation. The activities provided opportunities for participants to connect abstract astronomical concepts with observable phenomena and practical procedures. In particular, direct experience with telescope setup and eyepiece selection may have supported participants' understanding concepts that are difficult to learn through verbal explanations alone.

The findings are consistent with the principles of experiential and STEM-based learning, in which learners construct understanding through investigation, data analysis, technology use, and practical application. However, the results should be interpreted with caution because the study employed a one-group pretest–posttest design without a comparison group. Therefore, the higher posttest scores indicate improvement following participation in the activities, but they do not conclusively demonstrate that the developed activities were the only factor responsible for the improvement.

3.4 Participants' Perceptions of the Developed Activities

The opinions of the 30 pre-service physics teachers toward the developed STEM-based astronomy learning activities were evaluated in four areas: interest in the activities, perceived understanding of celestial coordinates and telescope use, STEM integration, and potential application in future teaching. The results are presented in Table 5.

Table 5. Learner opinions toward the developed activities (N = 30)

Indicator	Mean	SD	Perception Level
Interest in the activities	4.80	0.38	Very High
Perceived understanding of celestial coordinates and telescope use	4.73	0.45	Very High
Integration of STEM concepts	4.68	0.41	Very High
Potential application in future teaching	4.60	0.49	Very High
Overall	4.72	0.43	Very High

The results showed that the participants' overall opinion toward the developed activities was at a very high level ($M = 4.72$, $SD = 0.43$). Interest in the activities received the highest mean rating ($M = 4.80$, $SD = 0.38$), followed by perceived understanding of celestial coordinates and telescope use ($M = 4.73$, $SD = 0.45$). STEM integration was also rated at a very high level ($M = 4.68$, $SD = 0.41$), indicating that the participants recognized the integration of science, technology, engineering, and mathematics within the astronomy activities. Potential application in future teaching received a mean score of 4.60 ($SD = 0.49$), suggesting that the participants perceived the activities as applicable to their future professional practice. The high ratings may be associated with the activity design, which combined conceptual models, astronomy software, hands-on learning, and practical

telescope observation. These components provided opportunities for participants to connect abstract astronomical concepts with observable phenomena and practical applications. However, the questionnaire results represent the participants' perceptions and should be interpreted together with the conceptual understanding test rather than as direct evidence of learning achievement.

The findings demonstrated that the STEM-based astronomy learning activity package was systematically developed and was considered highly appropriate by the three experts. The overall expert evaluation was at a very high level ($M = 4.65$, $SD = 0.35$), particularly in terms of the learning process, content, and practical feasibility. These results suggest that the activity sequence, instructional materials, and integration of STEM components were appropriately aligned with the intended learning objectives. The use of the ADDIE model provided a systematic framework for analyzing the learning content, designing the activities, developing instructional materials, and revising the activities according to expert recommendations. This is consistent with Chamrat and Suyamoon (2024), who emphasized that STEM-based instructional design can support pre-service teachers in connecting disciplinary knowledge with practical teaching competencies.

The participants' conceptual understanding scores after the activities were significantly higher than their pretest scores. The mean score increased from 11.10 ($SD = 4.12$) to 23.50 ($SD = 2.46$), indicating substantial improvement following participation in the activities. This improvement may be associated with the activity sequence, which allowed participants to move from identifying celestial objects and coordinate positions to analyzing coordinate changes and applying their knowledge during telescope setup and observation. Rather than learning celestial coordinate systems through verbal explanations alone, the participants used celestial coordinate diagrams, physical models, astronomy software, and actual telescope observation. These learning experiences may have helped them connect abstract coordinate concepts with observable astronomical phenomena.

The findings are consistent with previous studies demonstrating the value of digital technologies in astronomy education. Fajriani and Masturi (2023) reported that astronomy applications could support students' conceptual understanding of celestial coordinates and digital literacy. Similarly, the use of planetarium and sky-simulation software has been found to help learners visualize the positions and apparent movements of celestial objects more clearly. Augmented and virtual representations can also provide learners with opportunities to examine astronomical phenomena that are difficult to observe directly in conventional classroom settings (Aggarwal et al., 2023; Chiang et al., 2019). However, the present study extended the use of digital representations by combining them with physical models and practical telescope activities. This combination may have enabled the participants to move between symbolic representations, simulated celestial environments, and real observational situations.

The item-level analysis showed notable improvements in concepts related to telescope operation and eyepiece selection. For example, the percentage of correct responses to the item concerning the use of a long focal-length eyepiece to obtain a wider field of view increased from 10% on the pretest to 90% on the posttest. Similarly, the percentage of correct responses to the item concerning the use of a short focal-length eyepiece to observe details of the Moon increased from 20% to 90%. These findings indicate that a greater proportion of participants selected the correct responses after completing the activities. The observed changes may be associated with the participants' hands-on experience in selecting and using eyepieces for different observational purposes. This interpretation is consistent with Kolb et al. (2018) and Slater (2018), who highlighted the educational value of telescope-based experiences in supporting practical astronomy knowledge and engagement with authentic astronomical observation.

The observed improvement in conceptual understanding may also be associated with the integration of inquiry-based learning, conceptual modeling, digital tools, mathematical

analysis, and practical telescope observation. During the activities, participants examined celestial coordinate information, observed patterns, analyzed changes according to observation time and location, used astronomy software and physical models, and applied their understanding during telescope setup and observation. These learning processes are consistent with the principles of integrated STEM education, in which relevant knowledge and practices from science, technology, engineering, and mathematics are connected through meaningful problems and practical applications (Bybee, 2013). The activities also provided opportunities for participants to compare their prior ideas with conceptual representations, data, and observational evidence. From the perspective of conceptual change theory, conceptual understanding may develop when learners recognize limitations in their existing explanations and encounter alternative explanations that are intelligible and useful (Posner et al., 1982). Nevertheless, because the present study employed a multiple-choice conceptual understanding test and did not collect written explanations or interview data, the findings should be interpreted as improvement in conceptual understanding rather than definitive evidence of deep conceptual restructuring or complete correction of astronomical misconceptions.

The participants' perceptions of the developed activities were also favorable. The overall perception rating was at a very high level ($M = 4.72$, $SD = 0.43$). Interest in the activities received the highest rating, followed by perceived understanding of celestial coordinate systems and telescope use, integration of STEM concepts, and potential application in future teaching. These results indicate that the participants viewed the activities as engaging, understandable, and relevant to their future professional practice. The high level of interest may be associated with the combination of physical models, astronomy software, data analysis, and telescope operation, which provided learning experiences beyond conventional lecture-based instruction. Lugo López et al. (2022) similarly reported that the combination of astronomical observation and three-dimensional simulations could support astronomy learning among teachers in training.

The participants also perceived that the activities could be applied in their future teaching. This finding is relevant because pre-service physics teachers require not only astronomy content knowledge but also experience in selecting instructional technologies, organizing inquiry-based activities, and connecting theoretical concepts with observable phenomena. Previous studies have reported that pre-service teachers may continue to hold difficulties or misconceptions concerning basic astronomy concepts even after formal instruction (Ozkan & Akcay, 2016; Türk et al., 2015). Therefore, learning activities that allow pre-service teachers to examine astronomical concepts through multiple representations, digital tools, physical models, and authentic observation may contribute to both their astronomy content preparation and their ability to design meaningful astronomy learning experiences for school students.

Although improvements were observed, the findings should be interpreted with caution. The study involved 30 pre-service physics teachers from Years 1–3 at a single institution and employed a one-group pretest–posttest design without a comparison group. Consequently, the higher posttest scores cannot be attributed exclusively to the developed activities because testing effects, differences in prior knowledge, and other learning experiences may also have influenced the results. In addition, no separate pilot study was conducted before the main implementation. Future research should examine the activities with larger and more diverse participant groups, include a comparison group, investigate possible differences among year levels, and employ delayed posttests to examine the retention of conceptual understanding. Further studies may also use two-tier diagnostic tests, written explanations, classroom observations, or interviews to provide stronger evidence concerning changes in learners' astronomical conceptions.

4. Conclusion

This study developed three STEM-based astronomy learning activities focusing on celestial object identification, changes in celestial coordinates, and telescope setup and observation. The activities were evaluated by three experts and received an overall quality and appropriateness rating at a very high level ($M = 4.65$, $SD = 0.35$). The participants' mean conceptual understanding score increased from 11.10 ($SD = 4.12$) on the pretest to 23.50 ($SD = 2.46$) on the posttest, with the posttest score being significantly higher at the .05 level. Participants also reported a very high level of perception toward the activities ($M = 4.72$, $SD = 0.43$), particularly regarding interest, perceived understanding, STEM integration, and potential application in future teaching. These findings suggest that the developed activities have potential to support astronomy learning among pre-service physics teachers by connecting conceptual representations, astronomy software, physical models, data analysis, and telescope observation. However, the findings should be interpreted with caution because the study involved 30 participants from one institution and employed a one-group pretest–posttest design without a comparison group.

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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 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.

Ethics Statement

The research protocol was reviewed by the Human Research Ethics Committee of Surindra Rajabhat University, Thailand, and registered under project identification number HE692014. Prior to participation, all participants were informed about the purpose and procedures of the study, the voluntary nature of participation, their right to withdraw at any time without penalty, and the confidentiality of their personal information. Written informed consent was obtained from all participants before data collection. All participant information was kept confidential and used solely for research purposes.

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