



# Application of Utopia and Graxpert AI in Studying Celestial Objects to Support Research and Education Interests at the High School Level, and Public Outreach

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**Abstract:** UTOPIA is a remotely operated robotic telescope developed by Observatorium Astronomi Itera Lampung (OAIL) to support astronomy education and research. Integrated with an Android-based control system, it enables remote observations and is applied across different levels of astronomy education. This study integrates UTOPIA with GraXpert, an open-source artificial intelligence tool for astronomical image enhancement through background extraction and noise reduction. A program involving 30 senior high school students was conducted through guided celestial observations, data acquisition, and collaborative image analysis. Participants were introduced to optical telescope principles, CCD imaging, and basic astronomical data processing, while GraXpert was used to enhance nebular image quality and visualization. The effectiveness of the program was evaluated using pre-test and post-test assessments. Results show a significant increase in understanding, with the mean score rising from 10.33 to 25.10 and a normalized gain of 0.75, indicating high conceptual improvement. Questionnaire results indicate positive learning perception, with most participants reporting improved understanding of nebular objects and better comprehension of the UTOPIA system, reflected in dominant positive responses. These findings demonstrate that integrating robotic telescopes with AI-based image processing supports astronomy education and improves students' conceptual understanding through inquiry-based activities.

**Keywords:** Astrophotography; Education; GraXpert; STEM; UTOPIA

## Introduction

Astronomy is widely regarded as one of the foundational natural sciences, as it systematically investigates physical phenomena in the universe through observations of celestial objects and their interactions (Karttunen et al., 2007; Shu & Miles, 1983). Space serves as a natural laboratory that provides extreme physical conditions unavailable on Earth, enabling the study of fundamental processes governing matter, energy, and cosmic evolution (Bassi et al., 2022; Y. Huang et al., 2025; Jiang et al., 2026). Advances in

optics, spectroscopy, digital detectors, rocketry, and computational modelling have dramatically expanded the precision and scope of astronomical inquiry, reflecting the broader role of instrumental developments in driving progress in astronomy (Kuhn, 2020; Minardi et al., 2021; Rao et al., 2024). Modern observations across multiple wavelengths—from radio to gamma-ray—provide detailed insights into celestial objects, while also increasing the need for advanced data processing and interpretation (Takeuchi, 2025). Astronomical instrumentation like robotic telescope opens opportunities for the development of rapid data

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acquisition techniques and even the application of artificial intelligence such as convolutional neural networks implemented for lunar detection (Muztaba et al., 2023), and following computer vision successes for image contrast enhancement (Muztaba et al., 2022).

Image processing constitutes a critical role in enhancing visualization and extracting meaningful information from astronomical observations, enabling more accurate interpretation of celestial structures (Hong et al., 2024; Witwit et al., 2025). However, the increasing complexity of observational data presents challenges in educational contexts, as students and the public often require structured guidance to interpret scientific images effectively (Okulu, 2025). This highlights the need for instructional approaches that support both technical understanding and conceptual learning. The rapid development of science and technology has also facilitated the learning process through more practical and effective learning media (Aththibby et al., 2024; Ramdhani et al., 2024).

Astronomy also plays a strategic role in science communication as a bridge between scientific knowledge and society (Madsen & West, 2003). OAIL, the first public observatory in Sumatra, has developed educational and observational programs since 2016 and was formally inaugurated in 2018. These programs include astronomy education, observation activities, astronomy camps (Astrocamp), Olympiad training, and professional teacher development across multiple educational levels.

In line with its focus on educational outreach, the effectiveness of learning approaches used in these programs becomes an important consideration. Active learning approaches have been widely implemented in STEM education and have been shown to improve student engagement, conceptual understanding, and learning outcomes (Douglas, 2024; Freeman et al., 2014; Sidekerskienė & Damaševičius, 2025; Theobald et al., 2020; Wong & Shih, 2021). Active learning approaches have been widely implemented in STEM education and have been shown to improve student engagement, conceptual understanding, and learning outcomes (Contrino et al., 2024; Cooper et al., 2018; Deslauriers et al., 2019; Fedeli & Taylor, 2023; Freeman et al., 2014; Li et al., 2024; Medina Vásquez et al., 2025; Theobald et al., 2020; Wang, 2024). One such method, Think-Pair-Share (TPS), promotes individual thinking, peer discussion, and collaborative knowledge construction (LoPresto & Slater, 2016), and is effective in supporting critical thinking and conceptual understanding in science education (Gillies & Boyle, 2010). More recent studies further confirm the effectiveness of Think-Pair-Share (TPS) across various science learning contexts, for example in physics learning which requires conceptual understanding and problem-solving skills, as well as in

elementary science learning that emphasizes students' understanding of fundamental concepts such as changes in matter (T. A. N. Huang et al., 2023; Sya'diyah & Mulyani, 2025).

Despite the growing use of robotic telescope systems and active learning strategies, limited studies have examined their integration in astronomy education, particularly in the context of real observational data and image processing workflows. Observational outputs from robotic systems often require not only technical processing but also guided interpretation to support meaningful learning (Gomez & Fitzgerald, 2017). Therefore, integrating advanced instrumentation with structured learning methods such as TPS is essential to bridge the gap between data acquisition and conceptual understanding.

In this study, we utilize the UTOPIA telescope, a do-it-yourself (DIY)-based robotic telescope with Android-compatible control developed at OAIL, in combination with GraXpert for image processing. The novelty of this research lies in the integration of robotic telescope-based data acquisition, AI-assisted image processing, and TPS learning within an observatory-based educational setting. This study aims to analyze the development of participants' knowledge and their ability to interpret astronomical data following the implementation of this integrated approach.

## Method

This study was conducted as a public outreach-based learning activity in Cilimus Village, involving senior high school students as participants. The learning design employed the Think-Pair-Share (TPS) instructional model integrated with hands-on astronomical observation and digital image processing.

### *Instruments and Learning Tools*

The learning activity utilized the Ultra Compact Itera Robotic Telescope (UTOPIA) as the primary observational instrument and GraXpert 2.0 software for astronomical image processing. The UTOPIA telescope is a do-it-yourself (DIY) robotic system constructed using 3D-printed components and locally available materials, including aluminum extrusions, automotive bearings, and stepper motors. The system operates with OnStep firmware in an Alt-Azimuth (Alt-Az) configuration and is equipped with a 70 mm refractor and a CMOS imaging sensor, enabling automated celestial tracking and image acquisition through short-exposure (lucky imaging) techniques. GraXpert 2.0 was used for basic post-processing of astronomical images, particularly for noise reduction and background gradient correction.

*Think-Pair-Share Learning Implementation*

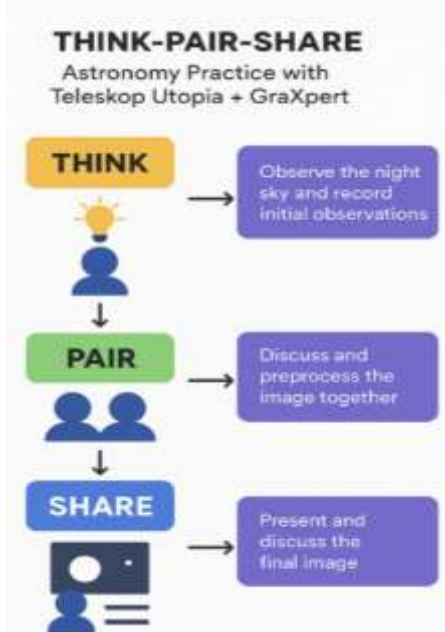
The Think-Pair-Share (TPS) learning model was applied in combination with hands-on astronomical observation using the Ultra Compact Itera Robotic Telescope (UTOPIA) and digital image processing using GraXpert 2.0 software (see Figure 1). In the Think phase, students were introduced to the basic concepts of star formation and evolution, with a focus on nebulae as stellar birth regions. Students were also guided to understand what can be observed from nebular objects and how observational data are acquired. In this stage, students individually operated the UTOPIA telescope under supervision to capture initial astronomical images and record observational data.

In the Pair phase, students worked in small groups to discuss their initial observations and collaboratively process the captured images using GraXpert 2.0. This included basic image enhancement, such as noise reduction and background gradient correction, to improve the visibility of nebular structures.

In the Share phase, each group presented their processed images and explained their interpretations of the observed astronomical features. Students were encouraged to relate the final image results to their initial understanding from the Think phase, followed by group discussion to reinforce conceptual understanding of star formation processes.

within the TPS learning framework. The analysis of learning outcomes was conducted using descriptive statistics, including mean scores, minimum and maximum values, and score distribution. This approach was employed to provide an overview of students' performance and to identify patterns of score improvement between pre-test and post-test results. Descriptive statistical analysis is widely used in science education research to summarize learning outcomes and support the interpretation of instructional effectiveness in pretest-posttest designs, particularly when combined with measures such as normalized gain (N-gain) to evaluate the magnitude of learning improvement (Arif et al., 2024; Pane et al., 2024; Putri et al., 2023).

Participant perceptions of the learning experience were evaluated using a post-activity questionnaire consisting of six indicators: (1) material clarity, (2) comprehension of learning material, (3) understanding of observational activities, (4) understanding of UTOPIA telescope operation, (5) adequacy of observation time allocation, and (6) effectiveness of the question-and-answer session in supporting understanding. The questionnaire was used to capture students' responses and perceived understanding as part of a comprehensive evaluation of learning effectiveness (Amalia et al., 2024). Questionnaire data were analyzed using descriptive percentage analysis to identify the distribution of responses across Likert-scale categories.



**Figure 1.** Applied Think-Pair-Share method for astronomical practice with UTOPIA and GraXpert

*Participants and Data Collection*

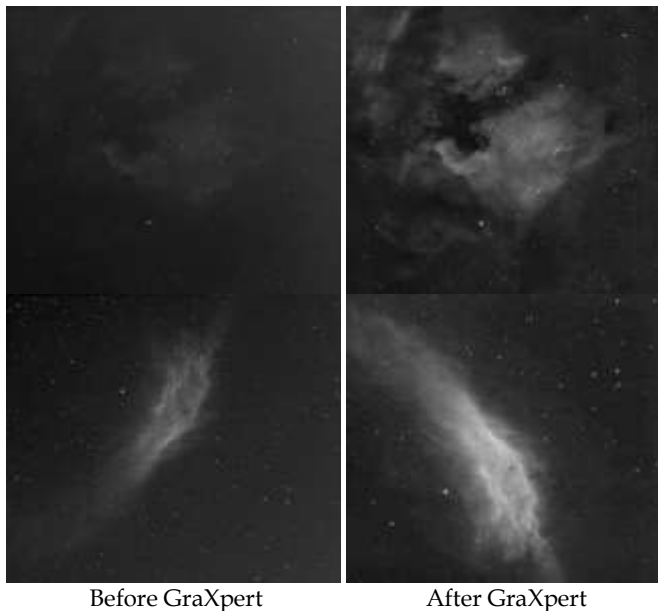
The study involved 30 senior high school students. Learning outcomes were assessed using pre-test and post-test instruments designed to measure students' understanding of astronomical concepts and skills

**Result and Discussion**

*Learning Tool Outputs*

The outputs generated from the learning tools are presented in Figure 2, which shows observational results of two nebular objects: (upper panel) the North America Nebula (NGC 7000) in the constellation Cygnus, and (lower panel) the California Nebula (NGC 1499) in the constellation Perseus. Both targets were imaged using the Hydrogen Alpha (H $\alpha$ ) filter. In the left-side (raw) images, which were directly acquired through the UTOPIA robotic telescope, the nebular structures appear relatively faint with low contrast and noticeable background noise. As a result, key morphological features such as filamentary gas distributions and regions associated with star-forming activity are not clearly visible. In the right-side (processed) images, after applying GraXpert, the visual quality is significantly improved. Background gradients and noise are effectively reduced, while contrast between dense and diffuse regions becomes more pronounced. This enhancement makes structural details within both nebulae more distinguishable, particularly the variations in gas and dust distribution that are relevant for identifying potential star-forming regions. The combination of raw observation and processed outputs

in Figure 2 illustrates the role of the learning tools in producing more interpretable astronomical images for educational use.



Before GraXpert                      After GraXpert  
**Figure 2.** (Upper panel) The North America Nebula (NGC 7000) in the constellation Cygnus. (Lower panel) the California Nebula (NGC 1499) in the constellation Perseus. Both imaged in hydrogen alpha filter

Figure 3 further shows how these outputs were directly incorporated into the learning process. Students engaged in both classroom discussion and outdoor observational activities, where the UTOPIA telescope was operated under guided supervision and the resulting images were collaboratively analyzed.

This demonstrates that the learning tools were not only used for data acquisition and processing, but also actively integrated into the Think-Pair-Share learning

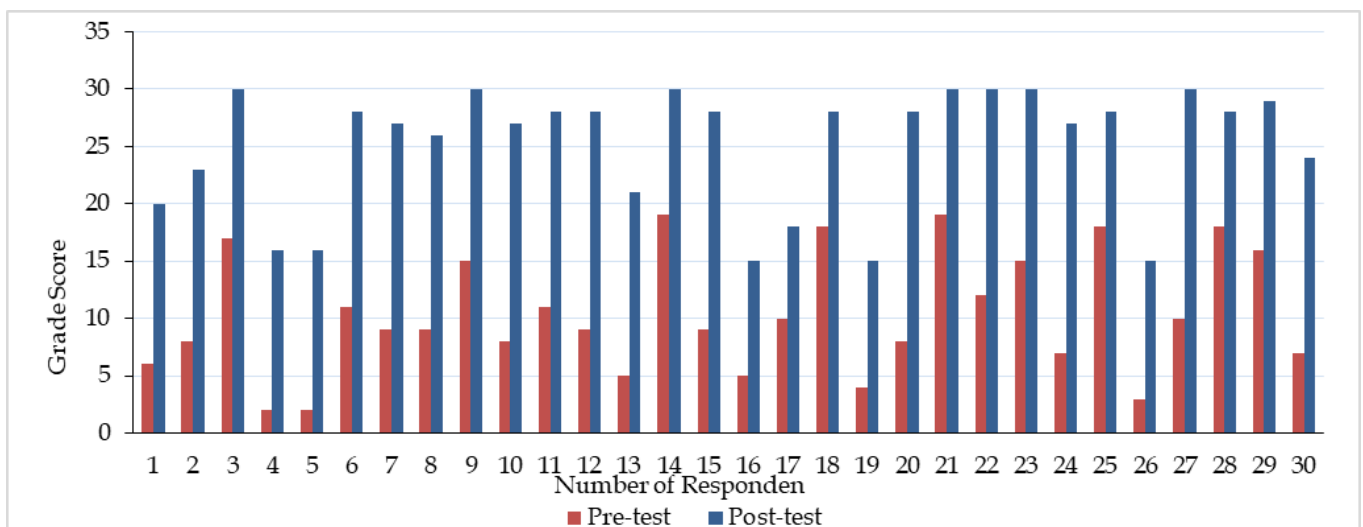
cycle to support interpretation and conceptual understanding. These findings are consistent with previous studies showing that collaborative and student-centered learning approaches enhance students' engagement, conceptual understanding, and ability to interpret scientific data, where Think-Pair-Share represents one form of structured collaborative learning (Arwaty et al., 2023; T. A. N. Huang et al., 2023; Irwandi et al., 2024; Sinuraya et al., 2024)



**Figure 3.** Classroom and outdoor activity

*Learning Outcomes Based on Assessment*

The pre- and post-test results, presented in Figure 4, illustrate individual learning performance across 30 students. The comparison between pre-test and post-test scores shows an improvement in all participants, indicating a positive learning gain after the instructional intervention.



**Figure 4.** Pretest, post-test, and gain score from 30 respondents

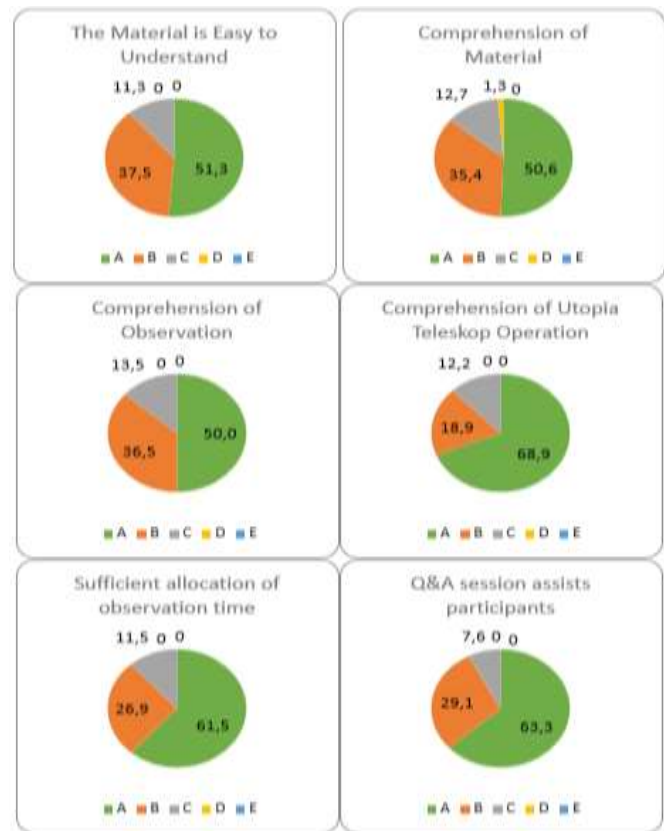
However, the magnitude of improvement varies among students, reflecting heterogeneity in prior knowledge and differences in their ability to assimilate astronomical concepts and observational experiences. This variation is likely influenced by differences in students' initial familiarity with astronomy-related concepts and their experience in interpreting observational data. Despite this variability, the consistent upward trend across all participants suggests that the learning intervention effectively supports conceptual development at the individual level.

**Table 1.** Comprehension Statistic Level from Pre-test and Post-test

Indicators	Pre-test	Post-test
Averages	10.33	25.10
Varians	27.75	28.71
Higher scores	19.00	30.00
Lower scores	2.00	15.00
Range	17.00	15.00

Following the improvement observed at the individual level in Figure 4, the analysis is extended by examining the overall distribution of scores using descriptive statistics presented in Table 1. The indicators include mean score, variance, maximum score, minimum score, and range, which collectively describe the distribution and improvement of students' understanding. The mean score increased from 10.33 in the pre-test to 25.10 in the post-test, indicating a substantial improvement in participants' conceptual understanding after the learning activities involving UTOPIA and GraXpert. Based on the mean pre-test and post-test scores, the normalized gain was calculated using the Hake gain formula, resulting in a value of 0.75, which falls within the high category. This suggests that the instructional approach was effective in enhancing learning outcomes. In terms of score distribution, the maximum score improved from 19.00 to 30.00, while the minimum score increased from 2.00 to 15.00. This indicates that not only high-performing students improved, but lower-performing participants also experienced significant learning gains. The range decreased slightly from 17.00 to 15.00, suggesting a modest reduction in score dispersion after the intervention, which may indicate a more uniform level of understanding among participants. However, the variance shows a relatively stable distribution, increasing slightly from 27.75 to 28.71. This suggests that although overall comprehension improved, variability among individual students remained present, likely due to differences in prior knowledge and familiarity with astronomical concepts and observational tools. Overall, these statistical results demonstrate that the integration of robotic telescope observation (UTOPIA), AI-based

image processing (GraXpert), and structured learning activities contributed positively to students' conceptual understanding in astronomy.



**Figure 5.** Grade of percentage understanding by administering a questionnaire following the activity

In addition to cognitive gains measured through pre-test and post-test analysis, the study also examined participants' affective responses toward the learning experience based on post-activity questionnaire data. The results, presented in Figure 5, indicate a consistently positive perception across all evaluated aspects. The response categories in the pie chart are based on a Likert scale, where A represents "strongly agree," B represents "agree," C represents "neutral," D represents "disagree," and E represents "strongly disagree." Responses were predominantly in the "strongly agree" category, exceeding 50% for all indicators, followed by the "agree" category, which ranged between approximately 18.9% and 37.5%. Meanwhile, neutral and negative responses were negligible across all aspects. These findings suggest that participants perceived the learning process as clear and engaging, demonstrated good understanding of both instructional content and observational activities, and responded positively to the use of the UTOPIA telescope and supporting learning structure, including time allocation and discussion sessions.

## Conclusion

The application of AI-assisted image processing using GraXpert successfully enhanced the clarity and structural visibility of nebular images, particularly in the California Nebula (NGC 1499) and the North America Nebula (NGC 7000). The resulting improvement in image contrast and noise reduction provided clearer visualization of nebular structures, thereby supporting the interpretation of star formation concepts in an educational context. The integration of the Think-Pair-Share (TPS) learning model with UTOPIA robotic telescope observations and AI-based image processing demonstrated strong instructional effectiveness. This is reflected in the substantial improvement in students' conceptual understanding, where the average score increased from 10.33 (pre-test) to 25.10 (post-test), accompanied by a normalized gain of 0.75 (high category). In addition, questionnaire responses indicated a consistently positive learning perception, with more than 50% of participants selecting "strongly agree" across all evaluated indicators, reflecting high levels of perceived clarity, engagement, and understanding of both observational and analytical activities. Despite these positive outcomes, the implementation remains influenced by limitations related to observational conditions and instrument stability, which may affect the consistency of raw astronomical data acquisition. Overall, the findings confirm that the integration of robotic telescope observation, AI-driven image enhancement, and collaborative learning strategies provides an effective framework for improving astronomy education at the secondary school level.

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## Author Contributions

Conceptualization, R.M. and I.W.; methodology, I.W.; software, A.A.Y; validation, R.M. and R.A.; formal analysis, R.M.; investigation, R.M.; resources, R.M.; data curation, R.M.; writing—original draft preparation, R.M.; writing—review and editing, R.M. and I.W.; visualization, R.M.; supervision, M.R., S. and M.; project administration, R.A.; funding acquisition, R.M.

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## Conflicts of Interest

"The authors declare no conflict of interest."

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