



# The development and evaluation of an augmented reality-based armillary sphere for astronomical observation instruction



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## ABSTRACT

Based on kinesthetic learning style theory and interviews regarding teachers' experiences applying traditional astronomy teaching methods, a mobile digital armillary sphere (MDAS) using augmented reality (AR) was developed for use during astronomical observation instruction. The MDAS enables visual processes and limb movements similar to those that would occur in actual outdoor experiences to be employed in the classroom, thereby overcoming existing instructional limitations. A quasi-experimental design method was adopted, and 200 fifth-grade students were selected as participants. The use of the MDAS in astronomical observation courses affected students' learning effectiveness and interest. The experimental results indicated that using the MDAS system during outdoor observation activities effectively enhanced both the students' learning of astronomical observation content and their performance of astronomical observation skills. In addition, use of the MDAS effectively increased students' interest in astronomical observations and learning, which had a substantial effect on retention.

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## 1. Introduction

Compared to general subjects, astronomical observation instruction is a difficult topic to completely implement in natural science courses, primarily because the instruction depends on actual outdoor experience and observation, which is limited by time and location. However, astronomical observation instruction may be improved with the application of innovative technologies and instructional methods. Currently, considerable research on astronomical education employs novel interactive technologies to improve and assist in instruction (Morita, Setozaki, & Iwasaki, 2010; Schneps et al., 2014). However, these technologies have not been tested systematically (Duncan, 2005), and Slater (2008) has indicated that current technology-assisted astronomical instruction still has numerous unresolved issues. For example, in relation to scaffolding learning progressions, technological solutions have been untested, and additional limitations include lack of simulations, real scientific data, conceptual assessment instruments, virtual ongoing professional development, and pathways to enter the professional astronomical community.

In addition, as for the innovative instructional methods, Reid (1984) proposed the categorization of learning styles to produce more innovative instructional strategies for astronomical observation instruction (e.g., Alfonseca, Carro, Martín, Ortigosa, & Paredes, 2006; Dias, Sauaia, & Yoshizaki, 2013). A kinesthetic style of learning is one such category, and instructional activity design based on this learning style allows learners to achieve better learning effectiveness of astronomical concepts because of direct interaction between learners' bodies and the learning environment (Plummer, 2006). In Plummer's empirical study (2006), 60 third-grade and eighth-grade students used kinesthetic-style instructional strategies to understand celestial motion in the starry sky by using celestial simulation equipment in a planetarium. The results indicate that the combination of kinesthetic-style instructional strategies and artificial celestial scenarios in the planetarium generated positive effects regarding students' learning of celestial motion and formation of accurate concepts. Plummer (2006) also contended that during kinesthetic teaching activities, active learners exhibited better learning gains compared to passive learners.

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In recent years, with the rapid development of technologies such as the G-sensor, the digital compass, GPS, and high-speed mobile image processing equipment, it has become increasingly easier to apply the function of augmented reality on various mobile devices (e.g., smartphones and Pads). The kinesthetic instruction style has seldom been employed in information and communication technology applications for teaching because traditional technological devices were not particularly mobile. However, the emergence of innovative and highly portable mobile devices such as smartphones and tablet computers has generated an opportunity to implement kinesthetic learning with technological applications. These innovative technologies can contribute to vivid and realistic kinesthetic teaching designs and can enhance the effects of computer simulations.

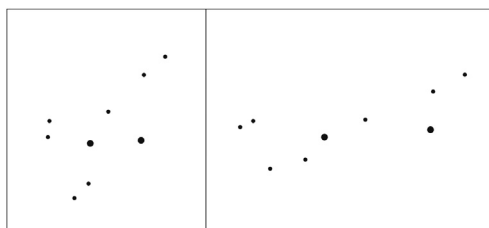
In addition to providing an innovative teaching method for astronomical observation instruction, mobile technology is beneficial for overcoming certain existing instructional limitations. In traditional classroom settings, numerous inevitable limitations exist regarding the execution of astronomical observation instruction. A primary objective of astronomy courses is to develop the students' skills in the outdoor observation of stars, which enhances students' understanding of the basic knowledge and concepts of astronomy and help to cultivate an interest in the subject. Therefore, actual outdoor experiences are crucial. However, the execution of outdoor instruction is dependent on various uncertain factors, such as weather or terrain conditions. These uncertain factors include light pollution, visibility, and climate; and the times at which specific astronomical phenomena occur are often at night and outside of school hours. These factors increase the risk of abnormality when conducting actual observations and hinder the practical implementation of astronomical observation instruction. Thus, astronomy courses tend to rely on in-classroom teaching with multimedia-assisted learning (e.g., textbooks, 2D wall charts, paper constellation disks, and slides). However, these teaching methods are limited and unable to cultivate students' skills in outdoor observation.

In Chandra's empirical study (2006) on students' misconceptions about astronomy learning, he applied the use of a computer-aided context-aware learning tool to increase students' understanding of the variation of astronomical phenomena in the four seasons. The results indicated that when students learn about abstract astronomical phenomena, fewer pictures or less information easily result in students forming misconceptions. Therefore, providing more pictures and information may improve students' understanding of astronomy learning. In previous studies, researchers indicated that textbooks with inappropriate paper-based information also lead to students developing misconceptions (Stavridou & Solomonidou, 1998). Observing the astronomical observation instruction, the use of inappropriate paper-based teaching materials, instead of more realistic computer simulation software, may provide improper information resulting in the formation of students' misconceptions. For example, the shape of Cygnus, often included in in-classroom paper-based planispheres, is easily misunderstood by students because the limitation of two-dimensional paper distorts the constellation's appearance (Fig. 1). Traditional instructional materials for astronomy primarily comprise 2D paper-based teaching aids, which restrict students' learning experiences to 2D concepts and increase the difficulty of comprehending the 3D depth and scale of astronomical and stellar configurations. Astronomical phenomena are difficult to accurately depict with 2D reduced models or illustrations. Therefore, students have to imagine and use intuitive thinking to understand celestial motion, which may lead to misconceptions. Typical examples of these misconceptions include that students suppose the celestial bodies orbit the Earth (the Fallacy of Geocentric Theory), Polaris never moves, there are no stars during the day, and various constellations have distorted shapes.

The learning dimensions of the procedural operations include the skills training of actual stargazing, tool use, and acquired prior knowledge. However, observation instruction is often simulated by paper-based planispheres in the classroom instead of delivered in an outdoor environment, thus resulting in more uniform action training. Teachers often give directions and ask students to use their fists to represent celestial bodies or assume that a certain corner in the classroom is represents north and ask students to determine the position of a constellation at a certain assumed time point by using planispheres. Because each reference of students' actions in stargazing during these classroom activities comes from their "assumptions", the same target that each students may point out the same location that may actually represent different positions. Also, on an actual instructional occasion, with the use of the traditional planispheres in a classroom to simulate the constellation observation, some students may show little interest in stargazing because it occurs in a simulated classroom environment. More even some students stare at the planispheres horizontally and omit to "raise their heads" which must occur on an actual occasion. A large difference between the above training and the actual actions of stargazing will lead to the restricted learning transfer in outdoor observations.

Regarding the implementation of astronomical observation instruction, several of the limitations mentioned above are caused by unrealistic teaching situations, which oftentimes reduce learning motivation. In addition, an inappropriate or insufficient provision of information causes students to develop erroneous assumptions. These limitations can be resolved with the application of mobile technology.

Numerous studies on mobile learning have suggested that mobile communication increases the effectiveness and availability of information networks, enhances students' learning-related activities at different locations, facilitates guided-tour activities, and elevates in-classroom communication and cooperative learning (Liu, Wang, Liang, Chan, & Yang, 2002; Sung, Chang, Hou, & Chen, 2010; Sung, Hou, Liu, & Chang, 2010). In addition, empirical studies have examined the integration of mobile learning with outdoor teaching. Ubiquitous theories of learning and context awareness dictate that mobile devices should be used as the primary tool for this type of integrated learning (Tan, Liu, & Chang, 2007). Furthermore, mobile devices (e.g., cellular phones and smartphones) are attractive to adolescent students and can therefore enhance learning motivation and increase concentration (Mifsud, 2002).



**Fig. 1.** The real shape of Cygnus in the sky (left); the illustration of wrong and distorted image of Cygnus in a paper-based planisphere (right), which is obviously condensed compared to the actual shape.

Implementing Augmented Reality (AR) via mobile devices to assist in astronomical observation instruction is a research issue worthy of investigating. Ronald Azuma defined three elements of AR in 1997: (1) it needs to combine the virtual with reality; (2) it can provide prompt interaction; and (3) it allows 3D positioning in space (Azuma, 1997). AR aims to provide a feeling to its users that are strongly similar to actual interaction with real environments. Additionally, through the display of virtual messages, users receive messages that they would not be able to receive from the real world. This feature is thought to encourage users to complete goals in the real world (Lee, Seo, & Rhee, 2011; Yim & Seong, 2010). AR has a significant effect on focusing learners' attention towards key learning objectives (Chang et al., 2014). Besides, with the subsequent discussion of the Augmented Reality technique, Cheng and Tsai (2013) conducted a meta-review on AR techniques and proposed that AR can be divided into two types: Image-based AR and Location-based AR. The present study posits that the Location-based AR model is well suited for learning activities in astronomical observations. An astronomy simulation software that uses the Location-based AR model is especially fitting for an astronomical instruction environment that is based on kinesthetic-style strategies. Through the gravity feedback from the learners' physical movements to the mobile devices, the learners can understand the status of their bodies at that moment (e.g., through the direction of vision focus and the elevation angle) to provide the star pictures within their field of vision, allowing it become a more precise astronomical observation tool. The application of Location-based AR to astronomical observation instruction has the following advantages:

1. In an in-classroom environment, the Location-based AR can provide a more realistic learning environment that promotes students' learning interest.
2. In an in-classroom environment, the Location-based AR can give a more accurate field of vision (FOV) simulation that will help to decrease students' misconceptions.
3. In an outdoor nighttime environment, the Location-based AR can improve the learning of astronomical phenomena without the limitations of weather, terrain conditions, and light.

In previous studies, some researchers have used Augmented Reality or Virtual Reality to provide astronomical instruction. For example, Morita et al. (2010) used an AR technique to display the correlations between celestial motions. Schneps et al. (2014) used a Virtual Reality technique to describe the proportions of celestial bodies. However, these studies were still limited to virtual scenes and lacked true interaction with an outdoor astronomical environment. Thus, the knowledge students gained was still wholly derived from their virtual experiences.

For this study, astronomy simulation software using AR technology was implemented in such a way that it enabled students to experience interactive learning within a real environment. This software reduces operational disparities between virtual or in-classroom observations and actual astronomical observations and therefore enhances students' real interactions with the environment. Employing this software will effectively eliminate the limitations of implementing and executing astronomy education and will prevent students from developing misunderstandings and erroneous assumptions by increasing the vividness of simulations, increasing learning motivation, and providing more precise and abundant simulation information.

## 2. Dilemmas in the teaching of astronomical observations

### 2.1. Instructor interview survey

Educators use specific instructional aids when teaching astronomical observation in traditional contexts. These educators usually have long-term experience in field observations of teaching situations and can easily identify students' learning difficulties. To understand the limitations of traditional teaching methods as a reference for our system's design, we interviewed eight full-time fifth-grade natural science teachers (2 men and 6 women) prior to designing the system. All of the interviewed teachers possessed more than 6 years of experience teaching fifth-grade natural science. The interview content was based on their experiences of astronomical observation instruction observed from the instructional occasions. Before being interviewed, the interviewed teachers were not given any hints about the various types of errors that are common in astronomical observation instruction. The interviews were open-ended and asked the respondents to share their experiences and opinions, including the limitations and problems they faced in their instruction. No time restrictions were placed on the interviews, allowing the teachers to express their opinions freely and completely without limitation. The teachers were also interviewed individually, ensuring they would not be influenced by other teachers' opinions. The interview questions were divided into the following two themes:

1. The explicit characteristics of barriers to student learning (e.g., a lack of interest or comprehension difficulties) for units that involve in-classroom astronomical observation instruction.
2. The behavioral characteristics of students in outdoor astronomical observation activities (e.g., whether the objective is successfully achieved, whether the target is successfully located, and the level of student enthusiasm during activities). The teachers describe the common problems and causes in students' learning.

According to the transcribed interview content, the various student error types mentioned were coded, and their frequencies were calculated. The various factors were summarized into six main factors that contribute to learning errors in astronomical observation instruction by the researcher (Table 1).

### 2.2. Related error factors

According to the summarized results of the teacher interviews, it appears there may be a possible relationship among the six main error factors. Through open-ended interviews, experienced astronomy teachers were asked about their astronomical observation instruction. A qualitative analysis of the interview answers was then conducted. Through coding, extraction, and integration, this study determined the correlations between six major error factors, representing the possible relationships between the common problems in astronomical

**Table 1**  
Learners' errors in astronomical observations and relevant contributing factors.

Code	Error type	Error factor	Error example	Frequency (N)
1-1	Failure to identify a constellation/primary star	Performance	Failure to locate Orion.	5
1-2	Incorrectly identifying a constellation/primary star	Performance	Mistaking Ursa Minor for the Big Dipper.	7
2-1	Incorrect angle of elevation	Operational	Searching for the target with an incorrect elevation angle.	8
2-2	Incorrect direction	Operational	Searching for the target in the incorrect direction.	8
2-3	General usage obstacles	Operational	Not knowing how to use a tool, or obtaining erroneous results when using a tool.	5
3-1	Cognitive error related to proportion	Cognitive	Mistakenly believing that Ursa Minor is larger than the Big Dipper.	6
3-2	Cognitive error related to shape	Cognitive	The W-shaped constellation arrangement of Cassiopeia is vague on the constellation disk compared to its actual appearance in the sky.	6
4-1	Lack of interest	Affective	A specific lack of interest in units related to astronomical observation and a tendency to become distracted. This phenomenon does not occur during other units.	8
4-2	Frustration	Affective	Frustration because of an inability to identify and recognize the contours and likenesses of constellations. An inability to identify a specific star that was identified correctly by most classmates.	8
5-1	Excessively complex tool operation	Tool	Learning to operate the constellation disk is necessary; however, students' learning achievements differ.	5
5-2	Sub-par tool precision	Tool	The accuracy of the clinometer regarding location is limited and its precision varies between users.	5
6-1	Disparity between teaching content and material objects	Environmental	Daytime in-classroom teaching instead of outdoor settings at night. Using simulated projections to teach.	7

instruction and their limiting factors. For example, environmental factors contribute to cognitive factors, and tool factors influence operational factors. The interviewed teachers all believed that in an inappropriate environment (e.g., indoors), it was inevitable that students would develop misconceptions regarding constellations. During outdoor observation activities, the use of inappropriate tools resulted in students feeling frustrated regarding operational factors. Furthermore, the combination of cognitive and operational error factors led to failure of performing astronomical observation techniques or skills (performance factor), which was the main factor that resulted in students' inability to identify constellations or correctly identify constellations, eventually resulting in frustration or loss of interest.

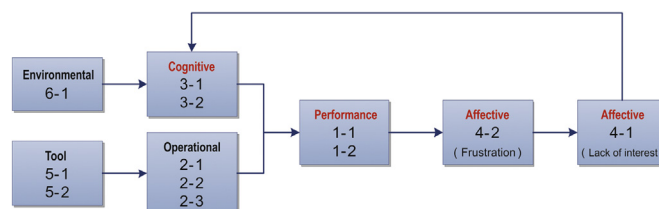
When learners lose interest in the learning objectives, they are likely to lose focus on the learning content, thus leading to further erroneous misconceptions. These cognitive errors are reflected in technical or skill performance. Students who maintain cognitive errors exhibit weaker technical performance and a higher probability of failure compared to their peers. This scenario generates frustration, which may be the primary cause of loss of interest; thus, a cycle is formed (Fig. 2). Conversely, if students are interested in learning, they actively engage with the learning content. Consequently, erroneous knowledge and misconceptions are less likely to be incorporated, and these learners exhibit better performance than their peers. This situation may significantly reduce the sense of failure or frustration, which are commonly experienced by astronomy students according to the interviewed teachers, during astronomical observation activities.

To increase students' interest in learning and their astronomical observation skill performance, the following two fundamental factors need to be emphasized: environmental factors and tool factors. Therefore, we replaced the tools used for relevant observations with the "Mobile Digital Armillary Sphere" (MDAS) proposed in this study and shifted the teaching environment (venue) to an outdoor location for cross-comparisons. The research objectives were as follows:

1. To determine whether improving the environmental factors and the learning tool is effective in improving cognitive factors (content acquisition and learning for astronomical observations);
2. To determine whether changing learning tools enhances performance factors (the performance of astronomical observation skills);
3. To determine whether an improvement in cognitive and performance factors improves affective factors (level of flow);
4. To determine whether an improvement in cognitive and performance factors prolongs the effects of affective factors (the level of flow was retested 30 days after the initial experiment).

### 3. System development

The MDAS, a teaching tool used in the instruction of astronomical observation, is equipped with the following functions that improve the disadvantages common to learning tools traditionally used in astronomical observation:



**Fig. 2.** The possible correlations of the six error factors.

1. All-weather (includes daytime and nighttime) stargazing functions reduce the adverse effects of environmental variables;
2. Stargazing functions are not limited by location (including indoor areas or areas that are exposed to light pollution), which also reduces the adverse effects of environmental variables;
3. An intuitive observation method is employed in which students can simply lift their heads to see stars, reducing the complexity of operations;
4. An intuitive information model enables students to instantly obtain related information when observing a star, thereby providing students with accurate concepts;
5. An automatic navigation for constellations allows students to rapidly search for specific targets, thus enhancing tool precision.

To achieve the aforementioned functions, the MDAS was designed based on the following three principles:

1. Mobility: Because portable mobile devices are used, operations can be conducted and the device can be transported with no limitations on location, which reduces the influence of environmental variables on astronomical observation instruction.
2. Specification: Through augmented reality, the target objects can be specified and synchronized with intuitive operations, limb movements, and information provision.
3. Accuracy: The tool was designed to fill the information gaps between digital data and real objects.

### 3.1. Mobility and specification

To meet the principle of mobility, the hardware environment chosen for the MDAS system was a mobile device. By combining a digital compass with a G-sensor, the MDAS also connects the target content with the users' physical movements to provide the experience of human–computer–field interaction. Microsoft Visual Studio.NET 2008 was adopted to develop the MDAS system, Windows Mobile 6.5 was employed for implementation and execution, and the HTC HD2 mobile hardware device was chosen as the carrier. To extract information from the G-sensor and the digital compass, a third-party plug-in (GSensorSDK.dll) was adopted for partial functions to conduct program compiling.

The framework of our system's operations and information flow is shown in Fig. 3. The digital compass (C) detects the user's torso rotations, and the G-sensor (G) detects limb movements. The detected data are analyzed using the system's Windows mobile core and GSensorSDK.dll, and the elevation angle and direction angle are calculated and transmitted to the MDAS. The MDAS calculates the user's FOV and then creates a star map on the smartphone's screen. The entire process of information flow involves real-time calculation; in other words, the displayed image changes instantly according to the user's physical (arm and body) movements.

To allow for ease of use and intuitive operation, no buttons are included in the system's interface. Instead, based on location and movement alone, the system promptly automatically displays constellation images (Fig. 4). The operational functions and menu are hidden within the touch interface. The touch interface provides three directional gestures (Fig. 5) that can summon a "time set function," a "system function menu," and a "guide tool." In the "time set function," the operator can set the time for his location to allow the system to display the current, past, and future star maps, enhancing the accuracy of the instructional application. The "guide tool" provides a directive function that permits the user to search for a specific star. The operator can touch the labels of a constellation or star he wants to search for, and a yellow directional line then appears on the screen to direct him to the celestial body. With this directive guidance, the operator is accurately led to the observed target (Fig. 6), and the user only needs to adjust the handheld device to the target direction or angle for the MDAS to display the pictures of the constellation FOV at the area immediately.

### 3.2. Accuracy

According to the mathematical principles of geometry, when a spherical figure is projected onto a planar or 2D surface, severe deformations occur in areas distant from the projection axis. The degree of deformation is directly proportional to the distance from the projection axis. This phenomenon can be clearly observed on world maps. On maps with an equatorial orthographic projection, the size and area of locations near the North Pole and the South Pole are highly disproportionate.

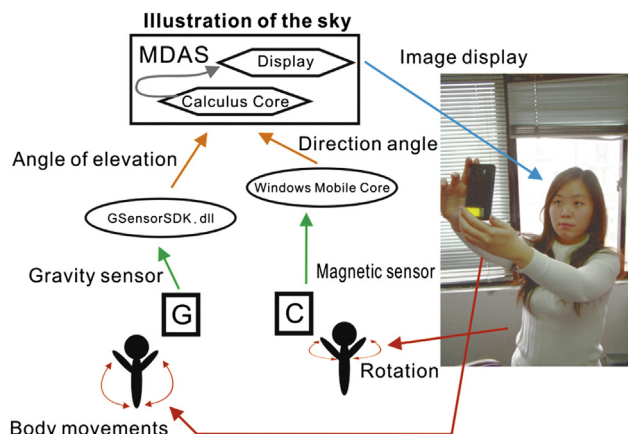


Fig. 3. The system operation and information flow transmission framework C, electric or digital compass; G, G-sensor.





Fig. 4. The operations of prompt constellation painting in the MDAS.

The starry sky is a spheroid and is called the celestial coordinate system. The image presentation methods in the majority of related software are confined and limited (e.g., to a screen), and spherical images must be projected onto a planar display screen. While the majority of areas adjacent to the projection axis are accurate and not substantially distorted, areas distant from the projection axis tend to be severely compressed and distorted because these areas are limited by the positioning of the projection axis (Fig. 7).

The location of the projection axis in traditional stellar projection methods is either vertical at an angle of  $90^\circ$  or horizontal at an angle of  $180^\circ$ , depending on the coordinate system but independent of the observer's angle of elevation. Therefore, the constellation image will be more accurate when the viewer's FOV is closer to the zenith of the celestial sphere, whereas the image of the horizon is considerably distorted. The MDAS adopts a dynamic projection axis calculation method in which the direction of the projection axis varies according to the center of the viewer's FOV, thereby illustrating again the star images within the viewer's FOV. Because of the limited FOV for the MDAS system, severely deformed images are located beyond the viewer's FOV; thus, the image in the viewer's FOV is always accurate.

### 3.3. Technical comparison

Since the MDAS was first developed in 2009, numerous similar software programs (e.g., Google Sky Map and Stellarium) have been developed. Due to the different goals of each software program, they each have some distinctions in terms of functionality. Some of the more concrete differences are as follows:

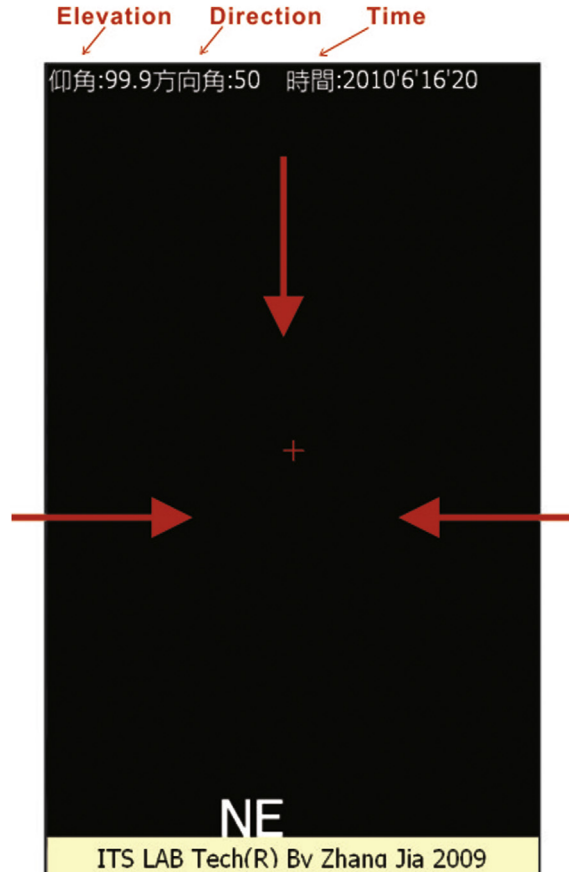


Fig. 5. The directions of three gestures to drag the function menus.

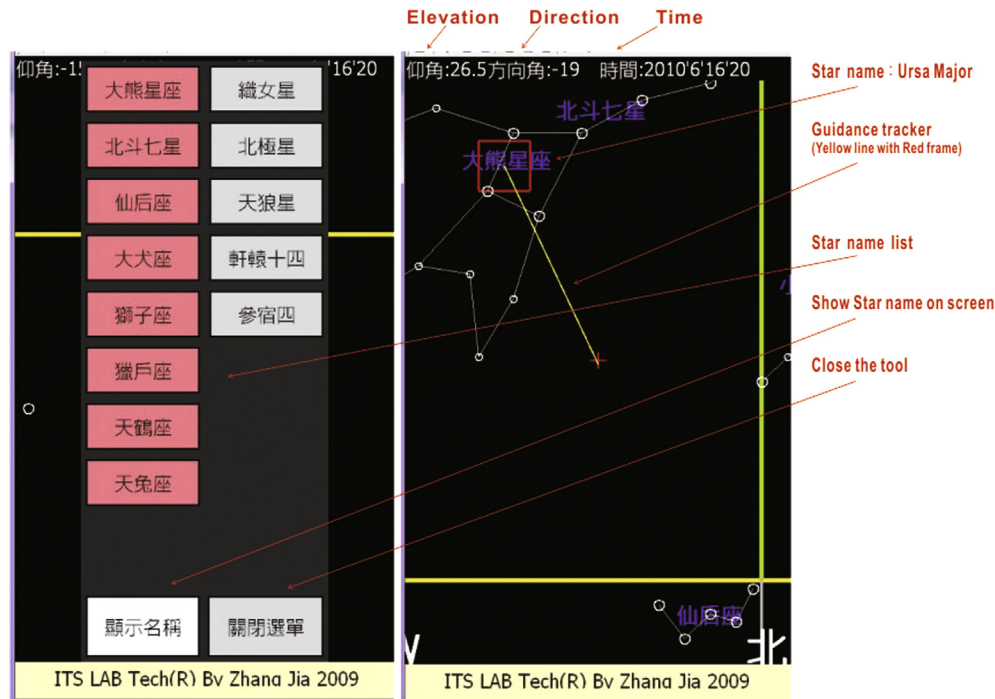


Fig. 6. Guide tool modules.

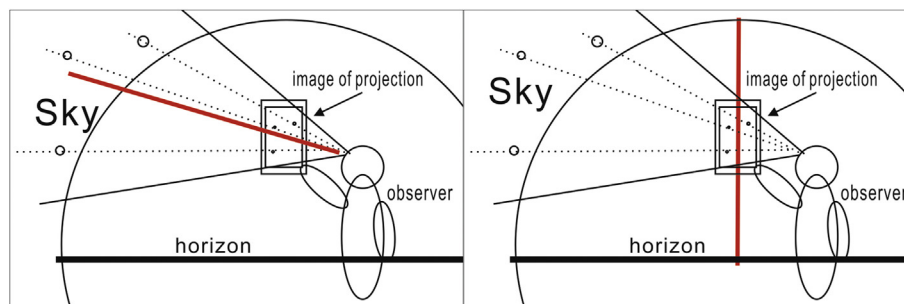


Fig. 7. Projection by traditional software (left) and projection by the MDAS (right).

1. Mobility: The MDAS and Google Sky Map can both be loaded onto mobile devices. They are portable, without limitation of environment. However, Stellarium needs to be loaded onto a desktop computer or laptop, effectively excluding usage outdoors.
2. Specification: The MDAS and Google Sky Map are able to directly respond to users' physical movements via the G-sensor and digital compass, as well as directly interact with the AR environment (kinesthetic-style strategies). However, Stellarium lacks a similar function.
3. Accuracy: The MDAS applies the dynamic projection axis calculation method to minimize the disparity between the information shown on the screen and the actual environment. This also ensures that the information the learner obtains is accurate, thus reducing misconceptions caused by the learning tool. However, Google Sky Map slightly deforms the images on the screen, and Stellarium has no relevant function for ensuring accuracy.

Based on these distinctions, the design of the MDAS best suited for instructional application. Compared to other software with similar functions, the MDAS has greater advantages for application during instruction in terms of the three aspects of mobility, specification, and accuracy. These strengths may help to reduce the limitations traditionally associated with astronomical observation skills instruction and their negative affect on student learning effectiveness.

## 4. Methodology

### 4.1. Participants

This quasi-experimental study included fifth-grade elementary school students. Students were assigned to the following 4 groups: traditional tools and in-classroom teaching (TC), traditional tools and outdoor teaching (TO), MDAS and in-classroom teaching (MC), and MDAS and outdoor teaching (MO). The TC group contained 40 students, the TO group 37 students, the MC group 34 students, and the MO group 36 students. The participants were recruited from various schools and classes using convenience sampling. Students were given

unique identifiers and were allocated to one of the four groups via computer-generated random numbering. The participants' final grades in natural science for the previous semester did not differ significantly between the four groups. The gender ratio was approximately 1.73:1 (boys:girls).

## 4.2. Procedure

### 4.2.1. Group

The motivation for and learning effectiveness of astronomical observation instruction were compared using various tools—traditional tools and the MDAS—and teaching environments (i.e., in the classroom and outdoors) to examine whether the application of the MDAS and the change in teaching environment increased learning achievement.

### 4.2.2. Experiment

In terms of the learning effectiveness, this study used the misconception examination questions as the learning achievement. This test examined whether students demonstrated any variance in their “learning of astronomical observation content” (the identification ability of the constellations) due to their use of different tools or due to the instructional environment. To investigate motivation, this study used the flow experience questionnaire proposed by Chang, Wu, Weng, and Sung (2012) to understand the immediate and delayed effects of their motivation and engagement on astronomical observation learning within different environments and with different tools.

A quasi-experimental design was used for this study. Regarding the experimental treatment, the TC group adopted traditional instruction—in-class multimedia instruction using paper-based planispheres—whereas the MC group used the MDAS to replace traditional paper-based planispheres.

The TO group adopted traditional planispheres, compasses, and angle finders to engage in outdoor stargazing, whereas the MO group used the MDAS to replace the traditional observation tools.

The TC and MC groups had in-class instruction for a total of 100 min, including 15 min each for the pretest and posttest and 10 min for the flow experience questionnaire. The TO and MO groups were given nighttime stargazing activities and outdoor instruction, which included 25 min for pre-procedures and explanations, 75 min for instruction, and 30 min for a constellation observation task. The amount of time allotted for the pretest, posttest, and the flow experience questionnaire were the same as the in-class groups. In addition, the outdoor groups (TO and MO) were given an extra test on locating seven stargazing targets to test whether the type of learning tool used affected students' astronomical observation skills.

All groups were given the learning achievement test as a pretest before the activity and as a posttest after the activity, and all groups also filled out the flow experience questionnaire after the activity. Thirty days after the activity, all students were given the flow experience questionnaire once again. In addition, students in MC and MO groups were given operational training in the MDAS before the experiment so that they could adapt to using the equipment, thus decreasing the likelihood of technology implementation obstacles during the experiment.

## 4.3. Research tools

### 4.3.1. The learning achievement test

The learning achievement test questions were chosen by eight elementary natural science teachers and one expert in the teaching material design of the astronomical observation based on the content of the fifth-grade constellation observation unit. The questions were divided into three dimensions: constellation identification, constellation proportion, and constellation deformation. The constellation identification section had a total possible score of 16 and was composed of realistic constellation images to test students' ability correctly identify celestial bodies. A higher indicator demonstrates that students can successfully identify a target star during actual observation. The constellation proportion section had a total possible score of 12 and tested students' perceptions of constellation proportions. A higher indicator represents students' accurate perceptions; a lower indicator represents misconceptions of constellation proportions. The constellation deformation section, which had a total possible score of 8, was designed to test whether students had an accurate perception of constellation formation. A higher score indicates that students have fewer misconceptions about constellation formation. The learning achievement test was multiple choices and had a total possible score of 36, inclusive of three dimensions (Fig. 8).

The three indicators of the learning achievement test were collectively used to determine how learners' learning effectiveness was influenced by using different tools in different learning environments. The content of the pretest and posttest was the same. To ensure the reliability and the validity of the test, this study conducted a pretest on 203 fifth-grade students in elementary schools. The coefficient of internal consistency, Cronbach's Alpha, is 0.892. The effective sample size is 200.

### 4.3.2. Stargazing targets test

For the stargazing targets test, students were instructed to identify seven target stars or stellar configurations. One point was given for locating a correct target within 10 min using the tools provided, whereas no points were allocated if students failed to meet the criteria. The total possible score was 7, and the lowest possible score was 0.

### 4.3.3. The flow experience test

The flow experience test measurement in this study was a self-reported test modified from the flow concept and scale proposed by Chang et al. (2012). The measurement included three dimensions: the premises, the characteristics, and the results of flow. Each dimension contained seven self-reported questions that used a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The premise of flow was used to determine whether the participants were prepared to enter a state of flow and investigated factors such as prior knowledge and environmental conditions. An example of an item from the first dimension: When I am doing an astronomical observation learning activity, I am very clear on which problem I need to solve. The characteristics of flow can be observed by the participant during an activity; that is, whether the participant experiences flow. An example of an item pertaining to the second dimension: When I am doing an astronomical



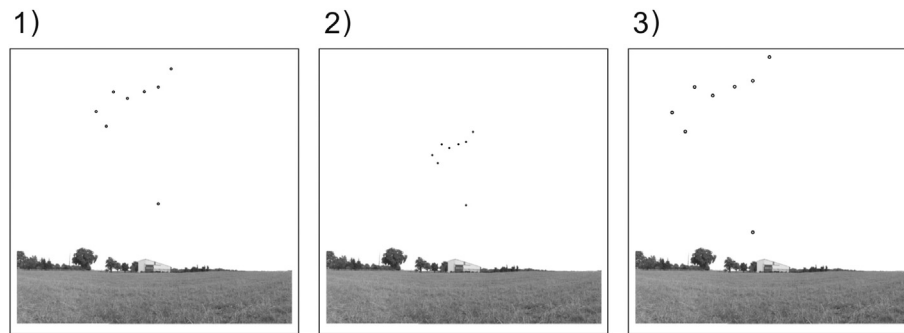


Fig. 8. Item examples from the learning achievement test.

observation learning activity, I am eager to keep going. Finally, the results of flow indicate whether flow is produced for the participant during an activity. An example of an item from the third dimension: When I am doing an astronomical observation learning activity, it feels like time is going by very quickly. These three dimensions together can be used to determine whether the participants achieved sufficient interest and a state of flow during the experimental activity.

## 5. Results

### 5.1. The knowledge of astronomical observations

The pretest and posttest scores of each group are provided in Table 2. The analysis of variance (ANOVA) results for the pretest revealed no significant differences in constellation identification ( $F(3,143) = 0.026, p = 0.994$ ), constellation proportion ( $F(3,143) = 0.786, p = 0.504$ ), and constellation deformation ( $F(3,143) = 0.414, p = 0.743$ ) among the four groups, indicating an equal level of astronomy knowledge for all participants before the experiment. On the posttest, however, significant differences were observed among the groups for constellation identification ( $F(3,143) = 11.021, p = 0.000$ ) and constellation proportion ( $F(3,143) = 5.460, p = 0.001$ ), whereas no significant difference was observed for constellation deformation ( $F(3,143) = 2.491, p = 0.063$ ). This finding suggests that different teaching tools and environments did not affect the participants' learning effectiveness regarding constellation deformation.

Scheffé's multiple-comparison method was used to compare the students' scores for constellation identification and proportion. The score for constellation identification was significantly better in the MO group than MC group ( $p = 0.000$ ), TC ( $p = 0.035$ ), and the TO group ( $p = 0.000$ ), but these results did not differ among the MC, TC, and TO groups, indicating that the combination of the MDAS and outdoor teaching was the most effective approach for improving the participants' constellation identification skills. The score for constellation proportion was significantly better in the MO group than the TO ( $p = 0.045$ ) and TC ( $p = 0.003$ ) groups, whereas the scores did not differ between the MO and MC groups ( $p = 0.386$ ). Furthermore, the scores were relatively the same among MC, TC and TO groups. In other words, although integrating the MDAS with outdoor teaching effectively enhanced the participants' cognition of constellation proportion, the primary factor that generated significant change was the implementation of the MDAS.

### 5.2. The performance of astronomical observation skills

The results of the seven stargazing target tasks showed that the score for identifying target stars or stellar configurations was significantly higher ( $t = -5.986, p = 0.000$ ) in the group that employed the MDAS (MO) than in the traditional learning tools group (TO).

### 5.3. Flow experience questionnaire and retention effect

The homogeneity test results indicated no significant differences between the four groups ( $p > 0.05$ ). Consequently, the ANOVA results indicated significant differences for immediate flow premises ( $F(3,171) = 8.596, p = 0.000$ ), characteristics ( $F(3,171) = 7.826, p = 0.000$ ), and results ( $F(3,171) = 9.020, p = 0.000$ ) among the four groups. The flow experience test was re-administered 30 days after the experiment, and

**Table 2**  
Descriptive statistical data for the learning of astronomical observation content.

Group	N		Pretest			Posttest		
			Constellation identification	Constellation proportion	Constellation deformation	Constellation identification	Constellation proportion	Constellation deformation
TC	40	Mean	6.30	5.10	6.40	7.40	6.00	6.70
		SD	3.831	3.622	2.182	4.205	3.948	2.289
MC	34	Mean	6.12	5.18	6.35	9.18	7.76	7.18
		SD	4.319	3.344	1.998	4.123	3.403	1.642
TO	37	Mean	6.27	6.16	6.70	7.24	6.81	7.14
		SD	3.203	4.173	1.898	4.199	3.985	1.669
MO	36	Mean	6.11	5.00	6.78	12.11	9.33	7.78
		SD	3.639	3.884	1.869	3.998	3.578	0.929

the post-30-day flow premises ( $F(3,171) = 22.130, p = 0.000$ ), characteristics ( $F(3,171) = 17.065, p = 0.000$ ), and results ( $F(3,171) = 14.165, p = 0.000$ ) also differed significantly among the four groups. However, the results of the paired-samples *t*-test revealed a significant deterioration in the level of flow for the TC, MC, and TO groups on the post-30-day test compared to the immediate test ( $p = 0.000$ ; Table 3).

Scheffé's multiple-comparison method indicated that the immediate effect for flow premise was better in the MO, TO, and MC groups than the TC group ( $p < 0.05$ ), but the results did not differ between the MO and MC groups. In regards to flow characteristics and flow results, the MO group was better than TO and TC groups, but there was no significant difference between the TO and TC groups. Therefore, regarding immediate effects, the use of the MDAS tool significantly improved the participants' overall flow status, whereas teaching location only affected the flow premise. When users employed the MDAS tool, the location had no significant effect on flow experience.

The results of the post-30-day retest showed that the retention effect of overall flow in the MO group (including premises, characteristics, and flow experience) was significantly higher than the other groups, indicating that the use of the MDAS tool combined with outdoor instruction can extend the effect of participants' flow experience.

## 6. Discussion and conclusion

An analysis of the results of this study allowed the following conclusions to be drawn:

1. Simultaneously improving environmental and tool factors is effective for improving the cognitive factors required for constellation identification and proportion (i.e., the learning of astronomical observation content).
2. In outdoor teaching environments, altering tool factors (i.e., using the MDAS system) significantly enhances performance factors (i.e., the performance of astronomical observation skills).
3. Improving cognitive and performance factors (i.e., the MO group) enhances affective factors (i.e., the level of flow), and this effect remains significant compared to traditional combinations or groups for 30 days afterwards.

The experimental results indicate that using the MDAS as a teaching tool for astronomical observations in an outdoor teaching environment enables students to achieve better learning achievements and to exhibit excellent skill performance. We found that the MDAS tool intervention was as important as conducting outdoor observation activities. Lai and Wu (2005) suggested that the key factors that influence the effectiveness of fifth-grade astronomical observation instruction are outdoor observations and the implementation of appropriate tools. Geary, Kelley, and Woodburn (1978) proposed that stargazing in realistic scenarios positively influences learning achievement, which is in line with the results of this study.

An analysis of the flow experience test revealed significant differences in the flow premises, characteristics, and results between the MO and MC groups and between the TO and TC groups. Thus, during astronomical observation instruction, the motivation of participants was affected more significantly by altering the tools used than by changing the learning environment. During the research process, students exhibited vivid emotional changes when the MDAS was employed for instruction. Students using the MDAS were significantly more active and engaged in interactions with the teacher compared to those students using traditional tools. In addition, the retest results of the MO group 30 days after the experiment indicated that the effect of the flow experience had a small-scale improvement. This was most likely due to that the MO group participants were able to more sufficiently experience a sense of reality and accuracy in an outdoor 3D astronomical observation learning approach than other methods of astronomical learning. When the MO group participants returned to the traditional classroom after the experiment, the results revealed that the participants continued to have an improved learning experience based on their prior outdoor 3D astronomical observation learning experience.

Astronomical observation instruction is a unique instructional activity that is highly dependent on practical and realistic teaching experience and is prone to interference from inappropriate or insufficiently accurate teaching materials that can result in learning errors. Auxiliary tools for astronomical observation instruction have evolved substantially over the years, from paper to digitized multimedia tools. The objective of improving these tools is to correct the inadequacies of previous observation teaching caused by tool or environmental factors. Through the design principles of mobility, specification, and accuracy, the MDAS tool has overcome the barriers to establishing human–computer–field experiences in astronomical observation instruction that were inherent with the use of previous auxiliary tools. This study shows that these design principles enhanced the effectiveness of learning about astronomical observation and the performance of astronomical observation skills. In addition, the introduction of augmented reality to construct a human–computer–field experience substantially increased learner motivation and had a stronger effect on the retention of learner interest in astronomical observation compared to traditional teaching scenarios.

With the assistance of innovative mobile technology, the benefits of a human–computer–field experience for astronomical observation instruction can be applied to improve the auxiliary tools for various types of outdoor teaching. These applications represent possible

**Table 3**  
Descriptive statistical data for the flow experience scale.

Group	N		Immediate			30 days		
			Flow premises	Flow characteristics	Flow results	Flow premises	Flow characteristics	Flow results
TC	43	Mean	20.63	21.40	17.88	17.21	18.74	16.40
		SD	5.936	5.985	5.885	5.365	5.508	5.819
MC	44	Mean	24.43	24.64	22.25	23.00	23.20	21.05
		SD	6.090	5.996	6.979	6.042	6.129	7.084
TO	42	Mean	24.67	22.07	20.33	23.69	20.95	19.57
		SD	5.520	4.561	5.621	5.875	4.659	5.692
MO	46	Mean	27.13	26.65	24.70	27.54	26.98	25.15
		SD	6.675	6.269	6.950	6.692	6.209	6.992

directions for the development of augmented reality-based human–computer-field experiences. In addition, future studies may further analyze the differences between the various astronomical observation AR tools designed for learning styles other than kinesthetic. This issue is worth exploring.

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