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# Teaching Physics through Astronomy: an object-based approach

# Teaching Physics through Astronomy: an object-based approach

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**Abstract**. Astronomy plays an important role in the cultural and scientific development of students, yet it is not always valued in upper secondary school. However, many Astronomy topics can be fruitfully addressed within the Physics curriculum. In this contribution, we present two workshops designed for in-service Physics teachers, aimed at proposing strategies for integrating Astronomy into the teaching of Physics. We chose light as the disciplinary focus, considering ray optics and spectroscopy as the specific topics. Valuing our collaboration with local Museums, we structured the workshops according to an Object-Based Learning (OBL) approach, enhancing the potential of scientific instruments for learning. During the workshops, the teachers experienced different ways of integrating Astronomy in the teaching of Physics through the use of instruments, and after the workshop they were invited to reflect on the usability of the proposed activities in the classroom. The findings suggest that OBL is a valuable approach for incorporating Astronomy into the Physics curriculum.

## 1. Introduction

Astronomy is the oldest of all sciences and continues to stand at the forefront of scientific research. Beyond advancing our knowledge of the Universe, it addresses profound existential questions, fascinating us and making us wonder about our place in time and space. The inclusion of Astronomy in school curricula across all levels of instruction has been repeatedly recommended not only for its scientific relevance, but also for its cultural, historical, practical, technological, aesthetic-emotional, pedagogical, and societal value [1].

Research in science education has long been engaged with the teaching and learning of Astronomy concepts [2]. Alongside generating findings about specific topics, these studies collectively endorse a longitudinal approach to Astronomy education, where concepts are addressed in a recursive manner from the early stages of education through upper secondary school [3]. However, practical reflections on the integration of Astronomy and Astronomy Education Research (AER) in the curriculum are relatively new [4]. The teaching of these topics is often a responsibility of Physics teachers. A relevant problem is therefore how to prepare them to meaningfully tackle this challenge and opportunity.

## 2. Rationale

The project presented here is part of a broader initiative aimed at developing innovative instructional pathways that integrate Astronomy into the Physics curriculum. The main action within this initiative was ATENA (*Asiago TEachers Network on Astrophysics*), a year-long professional development program for Physics teachers that was launched in September 2022. The project is rooted in our prior experiences in Astronomy education [5-6] and it is based on the CoLLabora model for in-service teacher professional development, developed by the authors [7].

To introduce the program, we organized two workshops, called "*L'eredità di Galileo*" ("Galileo's legacy"). During the workshops, we explored the use of a strategy called Object-Based Learning (OBL), which is often used in museums, including scientific museums. In our case, the "objects" were scientific instruments, used to foster a more meaningful learning and students' engagement. The importance of instruments in Astronomy Education has been highlighted by previous research [3].

This contribution focuses on the design of the workshops and the response from the participating teachers. The twofold goal was to reflect on the integrated teaching of Physics and Astronomy and to experiment object-based teaching strategies. In particular, this study seeks to address the following research question:

[RQ] In which ways can object-based activities contribute to the integrated teaching of Physics and Astronomy?

## 3. Background and theoretical framework

### *3.1. Astronomy in the Italian upper secondary school curriculum*

The current directions for Italian secondary school curricula are contained in the "National Guidelines" [8], which establish the specific content and learning outcomes for all subjects taught across different types of schools.

Prior to the latest reform of upper secondary school in 2010, Astronomy was part of the "Science" subject, encompassing all natural sciences except for Physics, which is taught separately. The covered Astronomy topics included astronomical coordinates and distance measurements, astronomical quantities (luminosity, magnitude), the Earth, the Moon, and the Solar System, the Milky Way, spectroscopy, stellar evolution the classification and motion of galaxies, and the history, structure, and evolution of the Universe. The 2010 reform, however, significantly reduced the presence of Astronomy within the curriculum. The new Guidelines no longer mention these topics, except for introductory Astronomy concepts intended as a reinforcement of content learned in lower secondary school.

Nonetheless, opportunities for reintegrating some astronomical topics into the curriculum arise as we examine the "Physics" curriculum. Throughout the Guidelines for this subject, several references to astronomical content are found, such as the study of gravitation, the debate on cosmological systems, "historical problems that led to the new concepts of space and time, mass and energy" and " the most recent discoveries in Physics (e.g., in the field of Astrophysics and Cosmology or in the field of Particle Physics)" [8, p. 343].

### *3.2. Object-Based Learning and scientific instruments*

As the theoretical framework guiding the structuring of the workshop activities, we adopted Object-Based Learning (OBL). OBL is a form of experiential learning that involves the active integration of tangible objects into the learning environment [9]. At the core of the OBL perspective lies the idea that objects can serve as effective learning tools. The pedagogical approach of OBL involves the in-depth, multisensory exploration of tangible objects to enhance students' engagement and cultivate profound and meaningful learning experiences [10]. Objects are harnessed in various ways to foster both discipline-specific knowledge and transferable skills, such as communication, teamwork, practical observation, and drawing skills. Concurrently, they enrich the affective and emotional dimensions of learning, inspiring and captivating students [11]. Furthermore, objects can help elicit the intuitive interpretive models possessed by learners, supporting their evolution towards more structured ones [12].

In Physics and Astronomy, an important category of objects are the instruments employed for investigating phenomena. The study of scientific instruments also encompasses the exploration of Physics concepts underpinning their operating principles. Historical instruments are found and studied in museums and collections, the educational value of which has been often emphasised [13]. Museums represent an important context for non-formal science education, which can complement formal activities and enhance the quality of students' scientific literacy [14-15]. Through a historical lens, science is portrayed as an evolving process, characterized by facing difficulties and achieving breakthroughs. This historical perspective within the Physics curriculum has been shown to meaningfully contribute to students' learning [16].

## 4. Methods and participants

To address our RQ, we designed two workshops based on the principles of OBL as well as on the findings of Physics and Astronomy Education Research. The approach was to make the teachers experience the learning paths designed this way, and then reflect on their possible use in the classroom.

After each workshop, the teachers were asked to individually answer the following questions:

- Among the activities you have experienced in the workshop, which ones could you employ in your classroom?
- What learning outcomes could these activities contribute to?
- What challenges and opportunities do you perceive?

The questions were delivered through a digital platform. Teachers' responses were thematically coded to identify common trends and ideas, as well as discrepancies in teachers' views. Participants were 19 teachers, 16 of which teaching at a *Liceo Scientifico* (the other three taught at a non-scientific *Liceo*, a technical school, and a vocational school, respectively). Their academic background was in Physics (9 teachers), Mathematics (7), Astronomy (2), or Engineering (1).

## 5. The workshops

### *5.1. Light as red thread*

In designing the two workshops, we selected a fundamental concept in Physics that is also central in Astronomy: light. Electromagnetic radiation, the properties of which underlie many fundamental ideas of Physics, serves as our main source of knowledge about the Universe. Through light, we gain insights into the structure and composition of stars and celestial bodies; by studying spectra, we can gain information about the expansion of the Universe. Moreover, light provides a good example to illustrate the role and evolution of models in Physics. This aspect was underscored by focusing on two distinct interpretive models of light behavior: the ray model and the wave model, explored in the first and second workshop, respectively.

### *5.2. Integration of Object-Based Learning*

In outlining the activities, we considered the main findings from Physics and Astronomy Education Research, harmonizing them with the principles of Object-Based Learning. As mentioned above, in our case the "objects" were scientific instruments. Specifically, we incorporated instruments in each workshop through three distinct moments:

- For each workshop, we identified an instrument that could exemplify the explored light model. These instruments were the focus of a laboratory activity.
- Historical instruments were used as hooks to generate curiosity and questions about the topics of the workshop via a guided questioning activity.
- Each workshop encompassed a visit to a Museum (La Specola Museum of the National Institute of Astrophysics; Giovanni Poleni Museum of the History of Physics), with which our group had previously collaborated [17-18]. During the visits, the instruments were placed in the cultural and scientific context in which they were designed, highlighting their roles in the history of Physics and in the construction of scientific knowledge.

For the first workshop, focussed on ray optics, we chose Galileo's telescope. Historically, it was the first model of a telescope to be built, and it was used systematically by Galileo Galilei to study the sky. The use of this instrument paved the way for some of Galileo's fundamental discoveries, such as sunspots,

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the structure of the Moon's surface and its phases, Venus's phases, Jupiter's Medicean moons, and early insight into Saturn.

Galileo's telescope is a refracting telescope incorporating two lenses: a converging objective lens and a diverging eyepiece lens. The distance between the lenses is the absolute value of the algebraic sum of their focal distances (figure 1). The real image emerging from the objective lens is therefore placed on the focal point of the eyepiece lens, located beyond it. The eyepiece then magnifies the image generated by the objective lens, producing a non-inverted, virtual image located at infinity. This configuration is frequently used in instruments for terrestrial observation and small toy telescopes and it differs from the Keplerian configuration, where a combination of two converging lenses directly projects an image onto the crystalline. Compared to the Keplerian configuration, the Galilean one presents an opportunity to study the propagation of light rays through the lens components comprised in the telescope in a less trivial case.

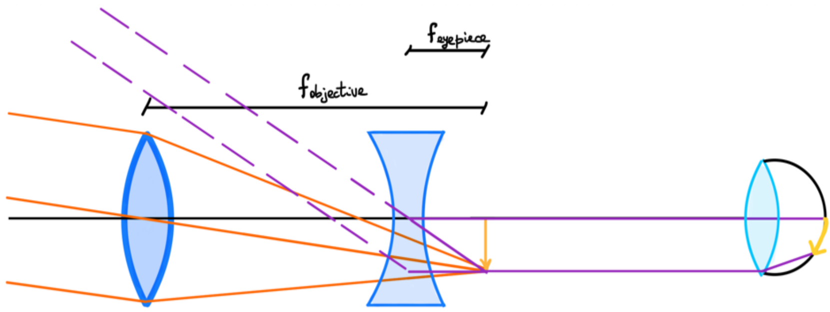
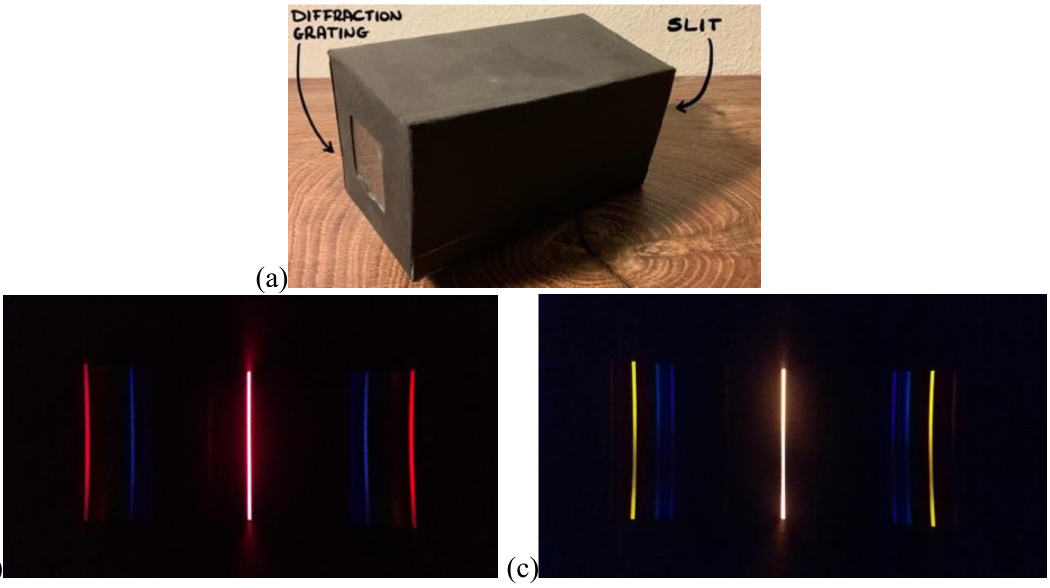



**Figure 1.** A scheme of Galileo's telescope. The upside-down image on the retina is reconstructed as upright by the brain.

For the second workshop, the chosen object was a pocket spectroscope employing a transmission diffraction grating as the dispersive element. Similarly to Galileo's telescope, the spectroscope represents a turning point in the history of Physics and Astronomy. In the mid-nineteenth century, Angelo Secchi pioneered spectral analysis for investigating stars and other astronomical objects. Starting from the distribution of colours and spectral lines, he inferred the chemical composition of some celestial bodies and initiated the first spectral classification of stars, thus giving birth to Astrophysics.

Examples of homemade versions of this spectroscope for educational purposes have been discussed in Physics Education literature [19-21]. It can used both for qualitative observation and comparison of spectra, as well as for some quantitative aspects such as estimating the wavelengths emitted from a source. In a previous project, we explored the use of this spectroscope within a teaching-learning sequence on atomic spectra for the fifth year of upper secondary school [22-23].

The pocket spectroscope was constructed from black cardboard (figure 2(a)). It was shaped as a parallelepiped where one of the bases was replaced with a diffraction grating (we utilized a commercial grating with a pitch of 500 ll/mm), while a small rectangular aperture was crafted in the other base. The spectroscope permits direct observation of the spectral decomposition of diverse light sources. By attaching the spectroscope to a camera (e.g., a smartphone's camera), spectra can be captured and used for further analysis. With simple adjustment to image settings, good images can be obtained, which can then be transferred to image processing software (e.g. Tracker).




(a) (b) (c)

**Figure 2.** (a) The pocket spectroscope and the acquired spectra of (b) hydrogen and (c) helium.

### *5.3. Workshop 1: Galileo's telescope*

The first workshop began with a visit to La Specola Museum of the National Institute of Astrophysics. Located inside the tower of an ancient castle, the museum preserves the historical heritage of the Astronomical Observatory of Padua, established in 1761. Although the Specola is no longer used as an observatory, the entire facility is now home to research activities in various fields of Astrophysics, as well as educational and outreach initiatives involving both schools and the general public. The teachers were guided through the museum's rooms, which house a collection of historical instruments including globes, quadrants, and telescopes from the 18th and 19th centuries (figure 3(a)).

After the visit, the teachers were hosted inside the La Specola facility, where they engaged in a laboratory activity centred around the construction of a toy replica of Galileo's telescope. The activity drew inspiration from the ISLE methodology [24], in which experiments are designed with an investigative approach and different types of experiments are considered [25]. The teachers were divided into groups and provided with an optical bench equipped with converging and diverging lenses, a light source, and a screen. Initially, teachers were encouraged to think about lenses and their properties. They were guided to recall the properties of the different types of lenses by looking through them or by using the optical bench. Converging and diverging lenses were characterized based on the properties of the image created (real/virtual, magnified/demagnified, upright/inverted), and teachers were invited to draw ray diagrams for each experiment.

Subsequently, teachers were tasked with sketching the structure of Galileo's telescope and realizing it on the optical bench, using the provided lenses (figure 3(b)). Reflecting on the properties of the image they would obtain from the instrument, teachers had to identify the desired characteristics of the objective and eyepiece lenses, as well as establish the optimal distance between them. Once again, teachers were encouraged to draw the ray diagram representing the light path inside the telescope. To test their predictions, they drew a small object on the screen and observed it through the lens system. Finally, the teachers assembled a toy version of the telescope using a cardboard tube of adjustable length and another set of unmounted lenses (figure 3(c)).

**Figure 3.** Some moments of the first workshop: (a) Teachers visit one of the rooms of the La Specola Museum. (b) Teachers assemble a model of Galileo's telescope on the optical bench. (c) A teacher verifies the functioning of the cardboard version of Galileo's telescope.

### *5.4. Workshop 2: Spectroscopy in a pocket*

This workshop began with a question-posing activity typically used in the OBL approach. The ativity consists in presenting participants with an object and encouraging all types of questions about the object. The underlying idea is that different facets of information about the analyzed instrument (e.g. color, shape, materials, decorations) can contribute to its comprehension. From a physics education perspective, this type of activity can also foster the ability of asking questions, a fundamental scientific practice [26]. In our specific case, four optical instruments from the Giovanni Poleni Museum were presented, each placed on a different table:

a) An 18th-century microscope (figure 4(a));
b) A prism-shaped object featuring several slots that could be filled with different liquids to study the behavior of light as it passed through them (figure 4(b));
c) An object comprising seven circular mirrors, each independently orientable, which enabled to reconstruct a white beam by reflecting and recombining the components of light (figure 4(c));
d) A glass prism and two lenses mounted on a base, serving as the innermost component of a spectrometer in which the prism was the dispersive element (figure 4(d)).

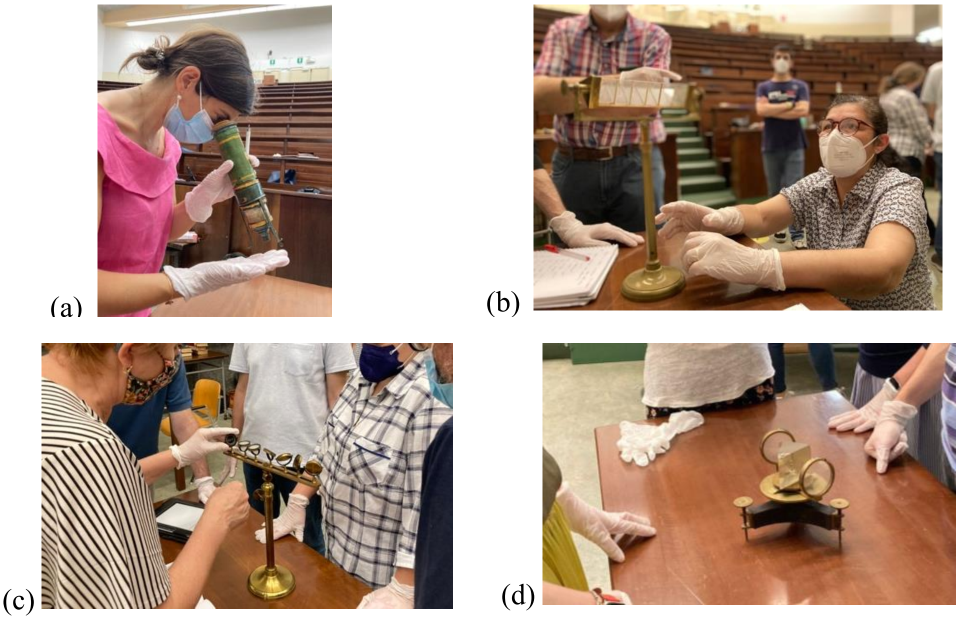


**Figure 4.** Teachers exploring four historical instruments.

The description of the instruments was deliberately not given to the teachers prior to the activity, and they were not asked to infer what the instruments were or how they worked. Instead, the teachers were encouraged to examine the objects and to write down all kinds of questions that came to their minds. All the formulated questions were collected and classified into six categories: context and history, technical and physical attributes, function and purpose, value, design and decoration, and creativity. Table 1 showcases a selection of the questions developed by the teachers as part of this activity.

**Table 1.** Questions elaborated by the teachers while exploring the instruments.

| | |
|---|---|
| Context and history | When/where was it built?<br>Who invented/ constructed/ commissioned it?<br>In what context was it used? |
| Technical and physical features | What material is it/its components made of?<br>What is the meaning of the shape?<br>Which types of lenses are there? |
| Function/purpose | What is it?<br>What is its function?<br>Was it used for teaching?<br>What is a specific component for? |
| Value | Does it have an economic value?<br>Is it a unique piece?<br>Is it a piece of a series? |
| Design and decoration | Is its colour important?<br>What is the meaning of the printed number? |
| Creativity | Is it to be used alone or with another tool?<br>Was it used in some specific laboratory?<br>Is it reported in any text? |

In the second part of the workshop we proposed the laboratory activity. Teachers worked in group to design a pocket spectroscope, starting from sketching a scheme of the instrument and reflecting on its components and their role. Their attention was then focused on the diffraction grating. They were invited to examine the behaviour of green and red laser light as it passed through a piece of grating mounted on an optical bench. Finally, they assembled the spectroscope and employed it to observe the spectra of different light sources, including the Sun, incandescent lamps, monochromatic sources, LEDs, and the fluorescent lamps of the room. Additionally, two gas discharge lamps were provided, enabling teachers to examine the spectra of hydrogen and helium (figure 2(b) and 2(c)).

The final activity was a visit to the Giovanni Poleni Museum of the History of Physics. The tour was focused on the museum section dedicated to optical instruments. Teachers had the opportunity to observe instruments relevant only to the wave model of light but also to the ray model explored in the previous workshop, such as telescopes, microscopes, prisms, and models of the eye.

## 6. Results

In the following we present an analysis of teachers' answers to the three questions posed after each workshop, which regarded (1) the possibility of integrating the proposed activities in the classroom, (2) the learning outcomes the activities could contribute to, and (3) the perceived challenges and opportunities.

Teachers envisioned different ways to bring the proposed activities to the classroom. The construction of the spectroscope was seen as particularly intriguing and at the same time feasible, especially when accompanied with pre- and post lab sessions. The design of Galileo's telescope was judged interesting, but also challenging for the students; some teachers suggested using a simpler configuration (such as the Keplerian one) while retaining the core structure of the activity.

Concerning the envisioned learning outcomes, some teachers mentioned content-related goals, such as understanding the type of lens from its properties, or using the thin lens formula to determine focal lengths, a concept that for many students remains rather abstract. The majority of teachers emphasised that these activities are expected to reinforce learning outcomes related to scientific practices and abilities (asking questions; modelling; conducting experiments; analysing data). This aligns with our laboratory design, focussed on the development of scientific abilities.

Among the opportunities, teachers highlighted the educational significance of the historical context, as for instance the story of Galileo's telescope. The object-based perspective along with the student-centred approach was appreciated; some teachers suggested extending this model to other object-based experiences, using objects such as students' eyeglasses. Teachers also enjoyed the visit to the museums, and many considered incorporating it into their teaching activities. Museums were described as knowledge-building sites where disciplines are intertwined and unified; they provide an historical context that frames the concepts of Physics and potentially leads to a deeper and more meaningful comprehension. Teachers also noted that while reaching Padua and its museums might pose challenges for schools located at a distance, local observatories and other Astronomy-related sites could be rediscovered and valued. Finally, the question-posing activity was deemed useful for introducing topics, as it engages attention, sparks curiosity, fosters cooperation, and helps familiarise students with the practice of asking questions, as opposed to being passive consumers of pre-packaged knowledge.

Teachers also pointed out some challenges. Some noted that including these activities in a lesson plan requires more time than typically allotted for the topic. On the part of some teachers, the idea emerged to incorporate these activities within a thematic path in the context of the so-called "*Percorsi per le Competenze Trasversali e l'Orientamento*" (PCTO) projects. These projects are complementary to the regular school activities and are now mandatory in Italian high schools; their aim is to strengthen students' transversal competencies and to guide them in their career choices. Some teachers also suggested to incorporate the proposed activities into multidisciplinary paths involving Physics, Astronomy, Philosophy, History, and Italian Literature (e.g., examining Galileo's texts).

Finding appropriate methods for assessing this type of activity was also a concern. One teacher suggested that assessment could be carried out by coordinating observations of students, individual/group reflections, and a final test, hypothesising that this multifocal assessment approach could favour richer and more personalised learning.

## 7. Conclusions and further development

The study presented here aimed at gaining insights into the following research question: *In which ways can object-based activities contribute to the integrated teaching of Physics and Astronomy?*

In the workshops proposed to the teachers, scientific instruments (the "objects") were used in different ways, inspired by research findings [3, 12, 18, 28]: laboratory activities involving the construction of instruments; the exploration of historical instruments; and the use of out-of-school contexts such as scientific museums.

Based on teachers' comments, we can identify some emerging themes. The construction of instruments, promoting a deeper understanding of their functioning, was seen as very useful for the development of different scientific practices and abilities, a pivotal element in physics education [26, 29]. From the point of view of content, teacher emphasized some physics topics that can be enriched by the astronomical context and the use of instruments. In particular, the activities were seen as a good opportunity for delving deeper into the understanding of optics through its applications and their use in astronomical observations. Finally, scientific museums and narratives about historical instruments can favor an increased awareness of the tight connection between the development of science and the advancement of technology, a relationship that is very important also today.

This feedback encouraged us to use elements of the OBL approach in the development of ATENA, the year-long teacher training program that followed-up the two workshops. During this program we delved deeper into the study of light and its connections with astronomy through the exploration of more instruments, such as quadrants, solar clocks, the "parallel globe" [27], and a home-made apparatus for measuring the speed of light. Further insights are expected from the school experimentation conducted as part of the ATENA program.

Our findings are initial and limited to a case study. However, we propose that Object-Based Learning should be further explored as a means to integrate Astronomy in the teaching of Physics. This approach aligns with recommendations from Astronomy Education Research [3] and is particularly suitable to integration with inquiry-based pedagogies and findings from Physics Education Research.

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