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Cosmo Hunters – a card game for middle-school (K12) Astronomy Education

Cosmo Hunters – gioco di carte per la didattica dell'astronomia nelle scuole secondarie di secondo grado

Rachele Toniolo[A,B,C*], Giannandrea Inchingolo[C,D], Alessandra Zanazzi[E,C], Silvia Casu[F]

[A] *University of Bologna, Department of Physics and Astronomy, Italy, rachele.toniolo@inaf.it**
[B] *INAF – Institute of Radio Astronomy, Bologna, Italy*
[C] *Game Science Research Center, Lucca, Italy, giannandrea.inchingolo@gmail.com*
[D] *IAU – OAE National Astronomy Education Coordinator Team for Italy*
[E] *INAF – Arcetri Astrophysical Observatory, Florence, Italy, alessandra.zanazzi@inaf.it*
[F] *INAF – Astronomical Observatory of Cagliari, Italy, silvia.casu@inaf.it*
** Corresponding author*

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ABSTRACT We explored the potential of the original card game Cosmo Hunters to engage low secondary school students and promote interest in astrophysical observations and the electromagnetic spectrum. We involved 175 Italian 13-years-old students and compared a game-based learning activity that used Cosmo Hunters with a frontal lesson with the same content. We tested the interest in the addressed scientific aspects before starting the activity, immediately after, and four weeks later. Overall, we concluded that our game-based learning approach is enjoyable and engaging. We also noticed that it enhances more efficiently the interest in the scientific aspects embedded in its game mechanics, i.e., the existence of different frequencies of the electromagnetic spectrum and the multi-frequencies observations used in astronomical research. We concluded that Cosmo Hunters can offer a compelling alternative to standard lectures for introducing and engaging the students with the basic concept of the electromagnetic spectrum and astrophysics observations.

KEYWORDS Game-Based Learning; Light; Astrophysics; Middle Schools; Card Game.

SOMMARIO Questo studio esplora il potenziale del gioco di carte Cosmo Hunters nel coinvolgere studenti e studentesse delle scuole secondarie di primo grado e promuovere l'interesse in merito ai temi delle osservazioni astrofisiche e dello spettro elettromagnetico. L'analisi ha coinvolto 175 studenti italiani di 13 anni e ha messo a confronto un'attività di didattica ludica basata su Cosmo Hunters e una lezione frontale con gli stessi contenuti. La valutazione dell'interesse è stata svolta prima di iniziare l'attività, alla fine e dopo quattro settimane. Si evince che l'approccio ludico è più coinvolgente, nonché favorisce l'interesse per gli aspetti scientifici incorporati nelle meccaniche del gioco, ovvero l'esistenza di diverse frequenze dello spettro elettromagnetico e le osservazioni multifrequenza utilizzate nella ricerca astrofisica. Si conclude che Cosmo Hunters è una valida alternativa per introdurre e coinvolgere studenti e studentesse in merito ai concetti base sullo spettro elettromagnetico e sulle osservazioni astrofisiche.

PAROLE CHIAVE Apprendimento Ludico; Luce; Astrofisica; Scuole Secondarie di Primo Grado; Gioco di Carte.

1. Introduction

The rising discipline of game studies has proven several times the effectiveness of board and digital games in promoting learning (Nesti, 2017). Indeed, they have the potential to create positive and enjoyable learning environments that can:

- offer a safe space – known as "magic circle" (Huizinga, 1949) – separated from daily life reality (Callois, 2001), which encourages free and creative experimentation;
- enhance motivation to learn (Bayeck 2020) by reaching a "state of flow" where players perceive themselves as able to overcome all the obstacles and challenges (Csikszentmihalyi et al., 2014);
- promote a learning-by-doing approach through active participation (Illingworth, 2019).

Research suggests that learning outcomes can be reached more effectively through game mechanics rather than the content alone (Bayeck, 2020; Yoon & Khambari, 2022). In particular, Andreoletti and Tinterri (2023) emphasized that the simulation of the aspects of a real system in a game helps players develop knowledge about how that system works. On the other side, while games that display explicit educational content are effective tools to reinforce learning (Cardinot & Fairfield, 2022), there is a risk of losing their appeal and, therefore, students' motivation and engagement, becoming "serious games" (Deterding et al., 2011). The intrinsic voluntariness that characterised games – as pointed out by Caillois (2001) – is then sacrificed when implementing a game in an educational context. Therefore, educational games must be carefully designed to maintain engagement (Ligabue, 2023).

To address this challenge, the first approach is to design tailored board games for game-based learning (GBL) activities to promote engaging science education. This approach is preferable for conveying complex scientific topics (Cardinot et al., 2022) but requires expertise in game design to create an engaging board game properly. For example, "Diamond: The Game" aims to promote scientific careers and experiences in secondary school students (Murray et al., 2022); "PIXEL – Picture of The Universe" makes players experience the processes and dynamics behind astrophysical research (Inchingolo et al., 2023; Toniolo et al., 2023); Cardinot and Fairfield (2022) developed a board game to enhance students' knowledge of astronomy concepts and perceptions of scientists; "Catan: Global Warming" is an expansion of a well-known commercial board game in which the game mechanics promote dialogue around global warming (Illingworth, 2019).

Another approach is to use commercial board games to create tailored GBL activities. In Inchingolo et al. (2024), we proposed an analysis of a ludography for space and astronomy education activities. We found a selection of board games that can be used for educational activities in middle and high school ages. However, the duration and complexity of some commercial board games require a tailored adaptation of these games when used in a school environment.

Despite the chosen approach with either commercial or novel board games, teachers and educators might face different challenges in designing GBL activities.

Choosing or developing a proper game requires high game media literacy (Swertz, 2019) and familiarity with games (Ligabue, 2023) to identify a suitable match for the activity. At first glance, most board game rules can appear confusing and hard to understand, and the number of rules can prevent a newbie gamer from enrolling in a game.

This factor also includes students, many of whom are not used to playing board games and, therefore, are not used to listening and understanding the rules quickly and keeping their attention on the activity (Ligabue, 2023).

The second challenge is the significant effort required from teachers/educators to prepare and implement the activity. Andreoletti and Tinterri (2023) summarized the various roles teachers can take on in GBL activities: player, instructor, guide, observer, director, assistant, initiator, referee, game character, subject matter expert, evaluator. All these roles unfold before, during, and after the activity itself, creating additional workload, which can prevent teachers from enrolling in such activities due to the high effort needed.

Moreover, Marklund et al. (2016) emphasised the need for contextualisation and a structured format to ensure that the playful activity achieves its educational goals, which further increases the preparation effort.

The third challenge involves time constraints within the classroom. The analysis paper of Inchingolo et al. (2024) showed that most of the astrophysics-themed board games on the market have a gameplay duration ranging from 60 to 120 minutes. This duration, added to the time needed to explain the rules and to do the educational debriefing after the play, makes it more challenging to fit GBL activities in educational sessions, which in Italian schools usually last up to of 100 minutes.

These challenges pushed us to develop and implement Cosmo Hunters, a card game that requires little or no familiarity with board games and has a gameplay lasting 20 minutes.

It aims to introduce, through game mechanics, the topic of astronomical observations of celestial objects at different frequencies of the electromagnetic spectrum with upper primary and middle school students (10-14 years old).

After the development, we tested the playability of Cosmo Hunters in different contexts with over 500 students aged 8 to 16, and we ended with the final version. In this study, we aim to test its potential to engage 13-year-old students and function as an educational tool to promote interest in the topic addressed right after the activity and four weeks later. To verify this, we compared our GBL activity using Cosmo Hunters with a frontal lecture covering the same educational topics of the game, involving 175 Italian students.

The paper is structured as follows. Section 2 provides a detailed description of the board game Cosmo Hunters. The methods used to conduct the analysis are described in section 3. The results are presented in section 4 and discussed in 5, while the conclusions are drawn in section 6.

2. Cosmo Hunters

In this section, we present Cosmo Hunters, the card game we developed for our GBL activity and the educational scientific messages we want to empower with this GBL activity.

Cosmo Hunters[1] is a card game for 2 to 6 players (up to 8 in pairs in educational activities) for people of 8+ years old; gameplay lasts 20-30 minutes. The game was developed by Giannandrea Inchingolo in collaboration with National Institute for Astrophysics (INAF) – Arcetri Astrophysical Observatory and GAME Science Research Center.

The game is used in GBL activities to introduce and discuss the basic concept of the electromagnetic spectrum and how astrophysics observations exploit it to study celestial objects with upper primary and low secondary school students (10+ years old).

The game was developed keeping in mind the three main challenges teachers face when implementing GBL activities in their classrooms, i.e., the game media literacy required to easily understand and explain/play new game rules, the effort to implement a GBL activity connected to this game, and the time constraint.

[1] Full description available here: https://play.inaf.it/en/cosmo-hunters-en/

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Figure 1. One Ultraviolet Observation card, one Infrared Telescope card and one Infrared Observation card. In this configuration, the player scores only 3 points on the Infrared Observation card because there isn't an Ultraviolet Telescope card.

In particular, to help educators use Cosmo Hunters for the GBL activities, we developed a guide for educators/teachers that will be provided together with the online free print version of the game. The guide is a collection of tips we collected in the various activities (including the ones for this study), additional material to use for the debriefing phase and a timeline to structure the activity.

The game mainly includes two types of cards, Observation cards and Telescope cards, divided into six frequency categories: Radio, Infrared, Visible, Ultraviolet, X-rays, Gamma rays. A third type is the Event cards, which introduce some variability in the game. The goal is to collect several Observation cards combined with the proper frequency Telescope card to score points and win. Each card in the game is associated with authentic astrophysics images of astrophysical objects and telescopes, making the setting even more evocative and deepening the scientific information on the cards.

Each Observation card represents a celestial object observed at a specific frequency of the electromagnetic spectrum. Players score points with the Observation cards if they have at least one Telescope card of the same category, as seen in Figure 1.

This mechanic mimics a basic mechanism in astrophysics research: to observe a celestial object, astrophysicists need an instrument (a telescope), which, however, is not sensible to all the frequencies of the electromagnetic spectrum. Therefore, they need specific telescopes for each observational band. The Telescope cards present the various types of telescopes currently used in contemporary astrophysics, showing that telescopes are much more varied in type than the common idea, e.g. the classic Galilean tube telescope on a tripod.

In addition, two sets of three Observation cards – characterised by a symbol – give extra points if collected together. They represent the same celestial object observed at different frequencies (Radio, Infrared, Ultraviolet and X-rays). See Figure 2 for an example.

Figure 2. Centaurus-A Galaxy Observation card in three different frequencies: Infrared, Radio and X-rays. All together, with their corresponding Telescope cards, are worth 15 points instead of 9.

Table 1. How the game mechanics we designed are linked with specific scientific aspects.

Scientific Aspects (SA)	Game mechanic
SA1. There are different kinds of light [frequencies of the electromagnetic spectrum] emitted by objects.	There are different kinds of Observation cards, each representing an electromagnetic frequency emission.
SA2. Different kinds of telescopes are used to observe celestial objects.	For every electromagnetic frequency emission, there is a corresponding Telescope card.
SA3. The same celestial object can emit different kinds of radiation at the same time.	Extra points can be earned if Observation cards of the same celestial object at different frequencies are collected.

This mechanic reproduces the astrophysics concept of multi-frequencies analysis: to properly understand the physics processes ongoing on a specific celestial object, astrophysicists often need to observe and study it at different frequencies of the electromagnetic spectrum, as each emitted frequency is produced by a particular process.

Table 1 summarizes the main scientific aspects introduced by the game through game mechanics.

3. Method

This study tests the potential of Cosmo Hunters to engage 13-year-old students in educational contexts and promote interest in the scientific aspects addressed and reported in Table 1.

We conveniently sampled 175 students in the last year of an Italian low secondary school (around 13 years old) in the city centre of Florence, in an area that is not too wealthy nor disadvantaged, with a certain number of students coming from immigrant families (around 12%).

Table 2. Compositions of the groups.

	Lesson group	Game group
Female	40	53
Male	36	46
Total	76	99

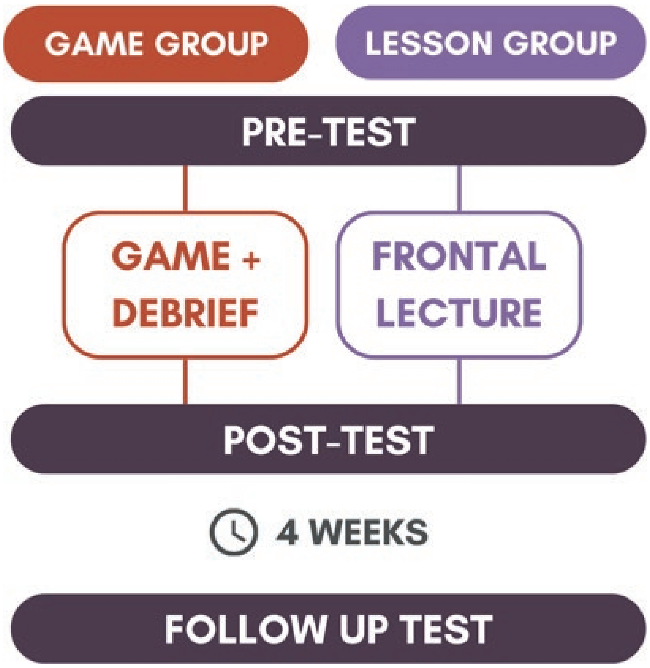

Figure 3. Timeline of the activity sessions conducted during spring 2024.

The decision to limit our study to 13-year-olds was made considering the Italian school curriculum, where the topic of light is briefly introduced at that age but still not deeply explored. Moreover, this target age is one of the more at risk for school drop-out, as reported by the report of the Italian Ministry of Education[2]. With our intervention, we aimed to involve students who are in a critical stage of their educational lives, in which they need to choose which high school is best for them.

We divided the students into two groups (Lesson and Game), as reported in Table 2.

We delivered a two-hour intervention to each group, as represented in Figure 3. For the Game Group, we delivered a GBL activity using Cosmo Hunters, followed by a debriefing session. For the Lesson Group, we delivered a frontal lecture with the same educational content conveyed by the game. For both groups, we administered a pre-test before starting the activity, a post-test at the end of it, and a follow-up test four weeks later.

The activities (GBL and frontal lecture) lasted 1.5 hours.

To the Game Group, we delivered a GBL activity that included gameplays of Cosmo Hunters, followed by a debriefing session of 45 minutes.

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[2] https://www.foe.it/files/2024/01/Focus-La-Dispersione-scolastica-aa.ss_.1920_2021-2021_2122.pdf

Table 3. List of questions presented in different tests (third column). The second column indicates the scientific aspects (SA) connected to this question in the game mechanics.

Question	Connected scientific aspect	Test
Q1: Recognise daily life objects that emit light [multiple-choice]	SA1	Pre and follow-up
Q2: List the types of light known [open-ended]	SA1	Pre, post, and follow-up
Q3: Identification of different kinds of telescopes [multiple-choice]	SA2	Pre, post, and follow-up
Q4: Identification of multifrequency astronomical observation [single-choice]	SA3	Pre, post, and follow-up

The students were divided into groups of 8 and played in pairs. This approach is effective in preventing students from feeling intimidated when playing the game for the first time and fostering the exchange of ideas and strategies, leading to a deeper processing and understanding of the topics (Ligabue, 2023).

The aim of the debriefing session is to reinforce the knowledge conveyed by the game, fostering the discussion between the students. In that part, the role of the facilitators is just to ask some questions related to the game to start the dialogue, guiding students to find the answers by themselves. See the Appendix for the questions used in this study.

The Lesson Group attended a frontal lecture delivered by astrophysics communication experts, presenting the same content introduced by Cosmo Hunters. Moreover, the images embedded in the lecture were the same as the game cards. The details of the lecture are reported in the Appendix.

It's clear that even if the lecture covered the same topics as Cosmo Hunters, the one-hour lesson allowed us to go deeper into the details of the topics with respect to the GBL activity within the same timespan.

The aim of the pre-test was to assess the students' previous knowledge of the electromagnetic spectrum and astrophysics observation. By comparing its answers with the ones of the post-test (delivered at the end of the intervention), we claim to evaluate whether the interest in the scientific topic addressed in the activity was raised in the students. This is demonstrated by the fact that they paid attention and therefore answered correctly to the questions. Furthermore, we assessed the long-term impact by delivering a follow-up test four weeks after the intervention. Answering each questionnaire took the students around 15 minutes.

Table 3 summarises the four main questions of the three questionnaires, which represent the source of data for this study. See the Appendix for a detailed description.

To design the evaluation tools of the pre-, post- and follow-up questionnaires and to design a correct debriefing part for the GBL activity, we involved a control group of 43 students of the same target age (13 years old) to implement their feedback in the final design of the educational and evaluation tools.

4. Results

In this section, we present the results of the pre, post, and follow-up questionnaires.

4.1. Engagement

In the post-test, we asked students about their perceived enjoyment of the activity. In Figure 4, we show the distribution of a Likert scale evaluation. The lower value (1) means "not at all enjoyed", while the higher one (7) means "very much enjoyed".

Figure 4. Answers to the question: "On a scale from 1 (not at all) to 7 (very much), how much did you enjoy the activity?".

We can observe that for the Game Group, the distribution has an average enjoyment of 6.0/7 and more than 75% of students replied with high enjoyment values between 6 and 7. On the other hand, the lesson group had a lower average enjoyment value (5.3/7) with more than 80% of replies between 5 and 6, and less than 4% replied "very much enjoyed" (7).

We can conclude that the game activity was more engaging than the lesson activity, and students engaged more with the game than the lesson, activating more emotional memory while doing the GBL activity.

4.2. Interest in the scientific aspects

We tested the efficacy of Cosmo Hunters as an educational tool to stimulate interest in the topic addressed by the game. To do so, we asked students to answer the four main questions reported hereafter (see the Appendix for further details).

- **Q1.** Recognize daily life objects that emit light. Multiple-choice between a series of 10 images.
  Only five are the correct answers.
- **Q2.** List the types of light they know [open-ended].
  In the pre-test, this question was formulated in relation to Q1, i.e., "Specify what type of light the selected objects emit"
- **Q3.** Recognize which instruments are telescopes.
  Multiple-choice between a series of 10 images. Only five are correct.
- **Q4.** Identification of multifrequency astrophysics observation.
  The question displays three images of the same celestial object seen through different frequencies. The answer is a single choice between four options.

The images of the objects of Q1 were chosen accordingly to establish literature on students' misconceptions about light and vision, e.g., the eye and mirror are often thought to emit light, as reported by (Besson, 2015).

Q1 and Q2 address the topic of the existence of different frequencies of the electromagnetic spectrum emitted by objects. The Game Group had the chance to experience it through the different types of frequencies depicted in the cards (Q2). These contents were also included in the lecture delivered to the Lesson Group. Moreover, during the debriefing of both groups, we fostered reflection about how some daily life objects can emit different frequencies (Q1) using the same images displayed in the questionnaire.

The goal of Q3 was to assess whether or not students paid attention to the images of the telescopes presented through the Telescope cards of the game, or during the lecture. In a similar way, Q4 tested if students truly understood the game mechanics related to multi-frequency observation. Indeed, the images presented in the test were those shown and discussed during the lecture and represented in the cards of the game.

Responses have been analyzed using multiple regression (for questions with a numerical score, i.e., Q1 and Q3) or logistic multiple regression (for questions with a single correct answer, i.e., Q4).

For Q1 and Q3, a value of 1 was assigned to each correct item that was selected and to each incorrect item that was not selected, while a value of 0 was assigned otherwise (the maximum score was 10). We summed up the values for every student and used these results to calculate the estimated marginal mean of scores using multiple regression analysis.

On the other hand, for Q4, we assigned a value of 1 when the correct response was selected and 0 to the other ones. The results were used to calculate the predicted probability of group scores using the multiple regression analysis.

Since Q2 is an open-ended question, we decided to calculate the percentage of correct or partially correct answers. We highlighted the presence of keywords of the electromagnetic spectrum, such as “radio”, “infrared”, “visible”, “ultraviolet”, “x-rays”, and “gamma rays”. We consider an answer correct or partially correct if it at least presents one of these highlights. Answers listing known other of light, e.g. “natural/artificial light”, “thermic light”, “led”, etc., were considered wrong.

The results of each analysis are reported hereafter.

Figure 5 shows the evolution of the estimated marginal mean of scores between the pre-test and follow-up of questions Q1. In the pre-test, it’s 7.08 with a standard error (SE) of 0.16 for the Game Group and 6.98 with SE of 0.18 for the Lesson Group, while in the follow-up it’s 8.38 with SE of 0.16 and 8.38 with SE of 0.18, respectively.

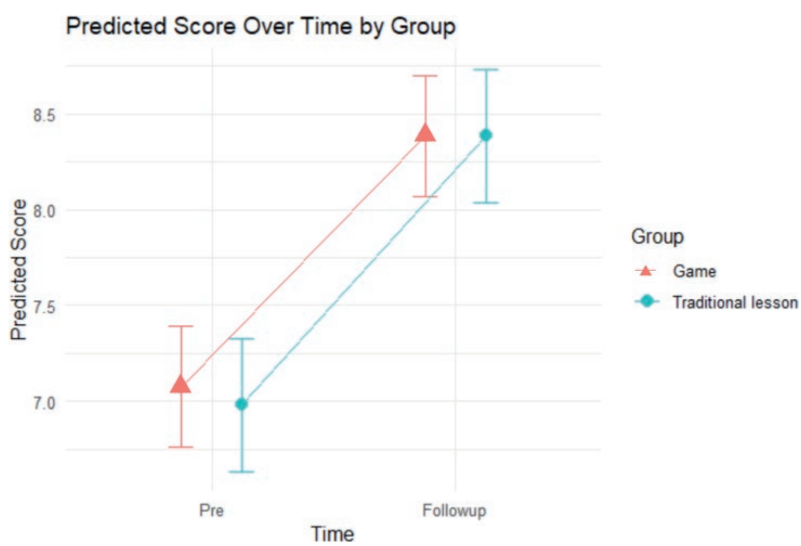

Figure 5. Predicted score over time of question Q1: “Which of these objects emit light?”.

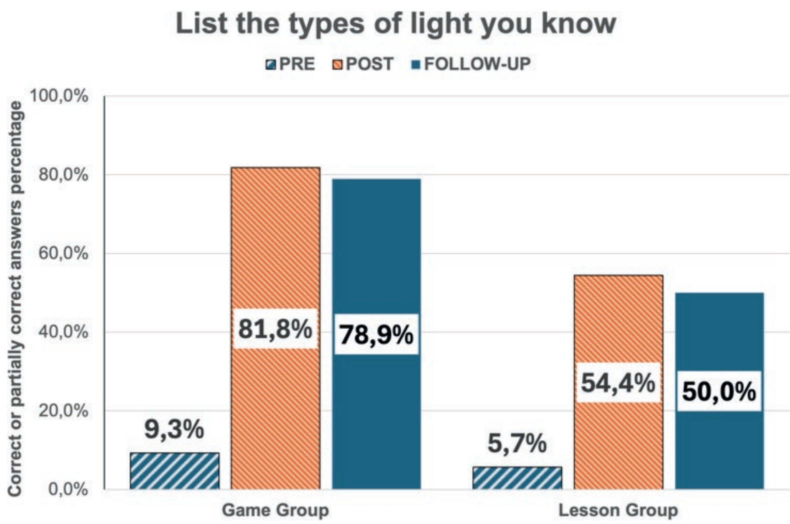

Figure 6. Correct or partially correct answers percentage to the question Q2.

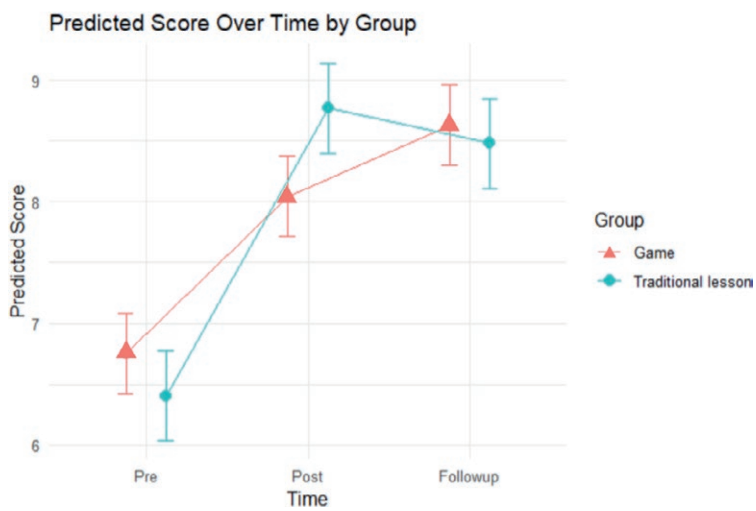

Figure 7. Predicted score over time of the question Q3: "Which of these are telescopes?".

The two groups show no significant difference in the estimated marginal mean of both phases since each mean values fall into the SE of the other one.

Figure 6 shows the results of question Q2. The Lesson Group performed a percentage of correct or partially correct answers of 5.7% in the pre-test, 54.4% in the post-test, and 50.0% in the follow-up test. On the other hand, the Game Group performed 9.3% on the pre-test, 81.8% on the post-test, and 78.9% in the follow-up.

For Q3 (Figure 7), the estimated marginal mean of scores in the pre-test is 6.75 with a SE of 0.17 for the Game Group and 6.40 with a SE of 0.19 for the Lesson Group, while in the post are 8.05 (SE 0.17) and 8.77 (SE 0.19), and in the follow-up 8.63 (SE 0.17) and 8.48 (SE 0.19), respectively.

We observe that both groups have the same prior knowledge about different kinds of telescopes, within the standard error. After the activity (post-test), the Lesson Group better recognizes telescopes

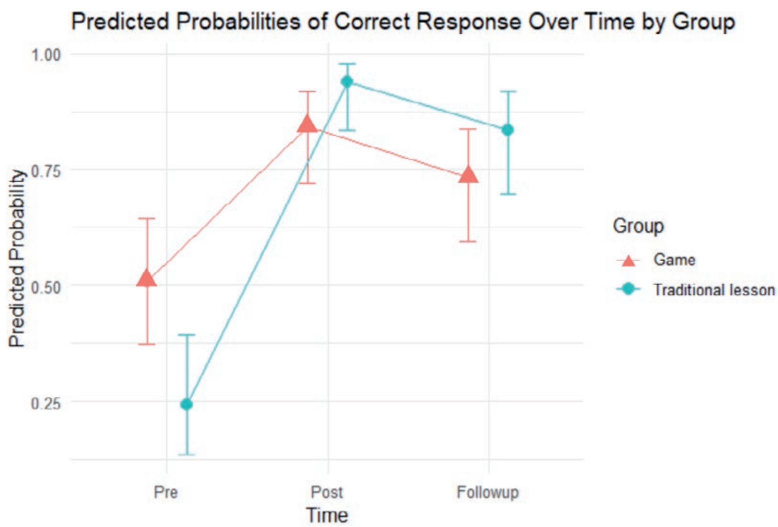

Figure 8. Predicted score over time of the question Q4: "What represents the three images shown here?".

than the game group. This result is likely because various types of telescopes are analyzed one by one and in more detail during the lesson. On the other hand, after four weeks (follow-up), the Game Group's response improves, becoming comparable to the performance of the Lesson Group.

The predicted probability of Q4, plotted in Figure 8, in the pre-test is 0.51 with SE of 0.07 for the Game Group and 0.24 with SE of 0.07 for the Lesson Group, while in the post are 0.84 (SE 0.05) and 0.94 (SE 0.03), and in the follow-up 0.73 (SE 0.06) and 0.84 (SE 0.06), respectively.

We observe that the Game Group had more previous knowledge about the images shown in question Q4 since they performed better than the Lesson Group in the pre-test. However, after the activities, the performances of the two groups are comparable within the standard error.

5. Discussion

The results shown in the previous section allowed us to better understand the potential of Cosmo Hunters to engage 13-year-old students in educational contexts and promote interest in the scientific aspects addressed in Table 1.

As expected, we observed that the GBL activity is more engaging than a classical frontal lecture in both average value and distribution (Fig 4). This is a typical result of innovative methods of education, particularly ones that involve games. The game is perceived as something new outside the classroom routine and, therefore, is more appreciated also because of the "novelty" effect.

Looking at the scientific aspects embedded within Cosmo Hunters, the results reported in section 4.2 proved that, overall, the GBL activity is able to promote interest with results comparable to a frontal lecture.

There are however some differences: regarding the nomenclature of frequencies of the electromagnetic spectrum (SA1), the Game Group reported more correct or partially correct answers than the Lesson Group. This result can be traced back to the intrinsic mechanics of Cosmo Hunters. The card mechanics require students to familiarise themselves with the nomenclature of the electromagnetic frequencies to play effectively. This helped to stick more firmly the nomenclature in the students' memory and to associate more deeply with the concept of the electromagnetic spectrum (which was later introduced during the debriefing), compared to a frontal lesson.

Another peculiarity lay in the results of Q3, regarding the images of the telescope (SA2). The Lesson Group performed better than the Game Group right after the activity, while the predicted scores were similar (no statistical difference) in the follow-up.

This is probably because, in the lesson, we had more time to deepen the nomenclature and visuals of different telescopes used for astrophysics observation. In the GBL activity, instead, both in the game and during the debriefing, we focused more on the necessity of having different kinds of telescopes for observing different frequencies rather than focusing on the nomenclature and visuals of these telescopes due to time limitations.

Furthermore, the understanding of multifrequency observation (SA3) is comparable for both groups in the post-test and the follow-up. It's worth mentioning that the SA3 in the GBL activity was conveyed more through a strategy choice than a game mechanic. Players can choose whether to collect Observation cards of the same objects at different frequencies to score more points or apply another strategy. This means that, even if there were no explicit push to multifrequency observation in the game, the strategic necessity to score more points via these card combinations leads to a deeper understanding of the astrophysical concepts, comparable with a frontal lesson.

We can conclude that Cosmo Hunters is an effective tool to engage and promote interest in 13-year-old students in educational contexts regarding the electromagnetic spectrum and astrophysical observations. The game is a valid alternative to a frontal lecture, with a higher engagement perceived by participants, and low effort required to implement it.

In particular, we observed that the scientific aspects embedded in Cosmo Hunters had different interest levels in the students according to the different ways they are implemented:

- SA1 is implemented as a core mechanic of the game. This is the primal level of engagement and access to the game and for this reason, the nomenclature of the electromagnetic spectrum used in this mechanic had a greater impact and interest for the students;
- SA2 is implemented both as a game mechanics (different telescopes necessary to observe) and aesthetic (different images for the different telescopes) of the game. For this reason, while the mechanic part of SA2 is interesting for students, the aesthetic parts asked in Q3 may be less interesting;
- SA3 is implemented as a game strategy, therefore requiring a more profound knowledge of the game dynamics to be perceived. Nevertheless, the simplicity of the Cosmo Hunters allowed to obtain an interest in this topic comparable to a frontal lecture.

This hierarchy of results is consistent with the literature that suggests that learning outcomes can be reached more effectively through game mechanics rather than the content alone (Bayeck, 2020; Yoon & Khambari, 2022).

6. Conclusion

Cosmo Hunters is a card game developed by Giannandrea Inchingolo in collaboration with INAF – Osservatorio Astrofisico di Arcetri and GAME Science Research Center.

Its goal is to introduce – in the span of a 15-20 minutes gameplay – the topic of astrophysics observations of celestial objects at different frequencies of the electromagnetic spectrum with upper primary and low secondary school students.

In this study, we tested the potential of Cosmo Hunters to engage 13-year-old students in educational contexts and to promote interest in three scientific aspects addressed by the game, i.e., the existence of different frequencies of the electromagnetic spectrum using astrophysics observation as a scientific context (SA1), the necessity to use different kind of telescopes for astrophysics observations (SA2), and the possibility to observe the same astrophysical object at different frequencies to have more information (SA3). We tested the engagement and interest effect of Cosmo Hunters compared to a classical frontal lecture and verified its long-term endurance after four weeks.

We involved two groups of students: the Game Group and the Lesson Group. The Game Group (99 students) attended a GBL activity composed of gameplays and a debriefing session, while the Lesson Group (76 students) attended a frontal lesson with the same content as the game.

The data collection was made through three questionnaires administered before starting the activity (pre-test), at the end of it (post-test), and after four weeks (follow-up).

Results showed that the GBL activity was perceived as more engaging than the frontal lecture. Indeed, the Likert scale evaluation reported an average enjoyment of 6.0/7 for the Game Group and 5.3/7 for the Lesson Group.

The analysis of the interest in scientific topics, on the other hand, gave different results for the three scientific aspects addressed by the game.

SA1, being a fundamental game mechanic, raised more interest than a traditional lecture. SA2, which was introduced through the aesthetic of the game, i.e., the images on the Telescope cards, proved to be more interesting in a traditional lecture than in the game. SA3 is addressed through a game strategy rather than a game mechanic. Therefore, it is tied to understanding the game's dynamics rather than just its rules, i.e., requiring more effort to achieve it compared to SA1. Even considering this aspect, the topic has obtained the same results compared to a frontal lecture.

From this analysis, we encourage using Cosmo Hunters as a GBL activity to introduce the basic concepts of the electromagnetic spectrum and how astrophysics observations exploit it to study celestial objects.

Moreover, thanks to the short duration of the gameplay (15-20 minutes), the game can also be used after the GBL activity in the class as a filler during free time – without preparation or intervention by the teacher – to reinforce the learning in a fun and enjoyable environment.

The game is fully described at play.inaf.it/en/cosmo-hunters-en/, and a Print&Play version of the game is also available to reproduce the activity in the classroom. We also developed a guide for facilitating the game-based learning activity that is available on the same webpage.

For future usage of Cosmo Hunters in GBL activities, we recommend doing a one-hour activity composed of a single gameplay followed by a debriefing of at least 30 minutes. For the debriefing, we reported the questions used in the Appendix as guidelines, and we suggest assessing in more detail the topics of multifrequency observation, improving the educational response of the students compared to the one obtained in this study.

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We want to acknowledge Marcello Passarelli for his contribution to the result analysis.

9. Appendix

9.1. Pre-test

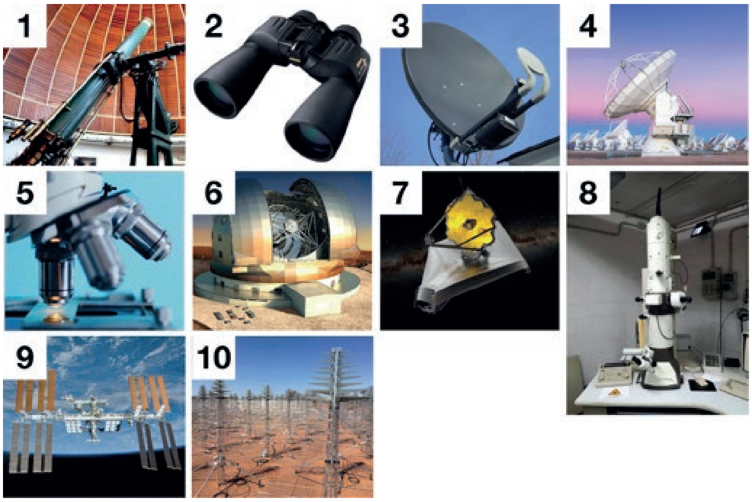
1) Which of these objects emit light?

2) Specify what type of light the selected objects emit.

3) What represents the three images shown here?

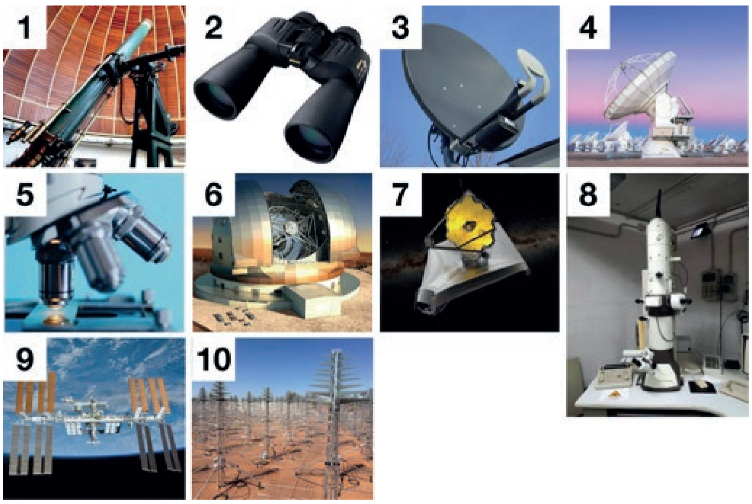
- o All the same nebula, but observed at different frequencies
- o A galaxy, a nebula, and a black hole
- o All galaxies, but of different types
- o All the same nebula but observed at three different stages of its evolution.

4) Which of these are telescopes?



9.2. Post-test

1) On a scale from 1 (not at all) to 7 (very much), how much did you enjoy today's activity?
2) Which of these are telescopes?



3) What represents the three images shown here?

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- o All the same nebula, but observed at different frequencies
- o A galaxy, a nebula, and a black hole
- o All galaxies, but of different types
- o All the same nebula but observed at three different stages of its evolution.

4) What types of light do you know?

9.3. Follow-up test

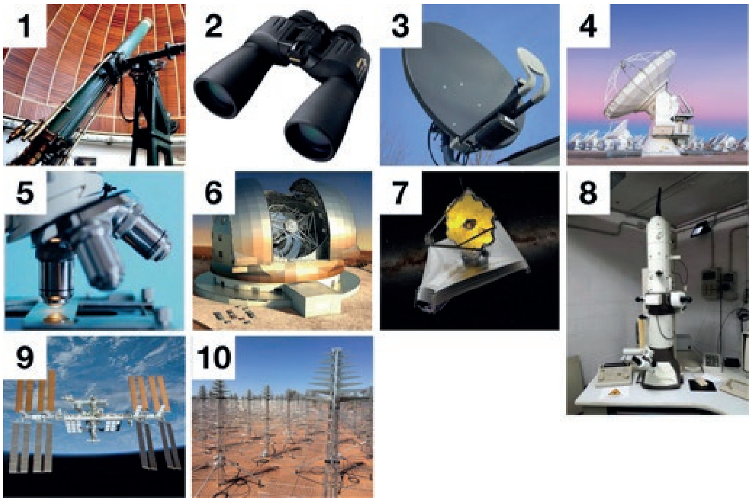
1) List the types of light you know.
2) Which of these objects emit light?

3) Arrange the following light frequencies from least energetic (lowest frequency) to most energetic (highest frequency). VISIBLE – X-RAYS – INFRARED – ULTRAVIOLET – RADIO – GAMMA RAYS – MICROWAVES

4) What represents the three images shown here?

- o All the same nebula, but observed at different frequencies
- o A galaxy, a nebula, and a black hole
- o All galaxies, but of different types
- o All the same nebula but observed at three different stages of its evolution.

5) Which of these are telescopes?



9.4. Frontal lecture

The frontal lecture comprehended the following arguments:

- what is astrophysics, and what does it mean to observe something (difference between light emitted and reflected)
- what is light (hints of dual nature)
- fundamental aspects of electromagnetic waves (wavelength, frequency, energy and their correlation)
- the electromagnetic spectrum (different kinds of light)
- different lights for different information (when studying a celestial object, it is important to look at every radiation emitted to obtain more details about its functioning)
- a detailed description of every frequency band (which kind of telescopes are needed to observe it, an example of a celestial object that emits it and how we use it in our daily lives)

9.5. Debriefing

During the debriefing, facilitators promote discussion among participants trough the use of the following questions. We highlight also that during the debriefing we used the questions of the post-test to simultaneously collect our data and use them to promote discussion along with the students:

- Did you have fun? What did you like the most, and what did you like the least?
- What were the winning strategies? What were the losing ones? Who won, and why did they win?
- Quick presentation of the main frequencies of the electromagnetic spectrum and their use in our daily lives
- [Display 10 image objects] Which of these objects emit light? Why?
- [Display 6 types of electromagnetic frequencies] Arrange the following types of light in order of increasing energy
- [Display the three Observation cards representing the same celestial object seen through different frequencies] Why do these cards give more points when they are collected together?
- Why do you need a corresponding Telescope card to score points with the Observation cards? For the Visible cards, it wasn't necessary. Why?

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- Brief explanation of the different type of telescopes.
- [Display 10 image instruments] Which of these instruments are telescopes?

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