IL NUOVO CIMENTO **48 C** (2025) 283
DOI 10.1393/ncc/i2025-25283-x

Colloquia: CooFIS08 2024 Researches

The role of natural language in understanding the universe: A teaching-learning sequence for high school students

M. Tuveri([1])([2]) and V. Fanti([1])([2])

([1]) *Physics Department, University of Cagliari - Cittadella Universitaria di Monserrato, 09042, Monserrato (CA), Italy*
([2]) *Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari - Cittadella Universitaria di Monserrato, 09042, Monserrato (CA), Italy*

received 2 September 2025

Summary. — Introducing gravitational physics in high school provides educational means for bridging the gap between the image of science held by students and science itself. Natural language is fundamental in this learning. It engages students in constructing an understanding of a concept or a notion, establishing new relations between previous and new elements of knowledge. We present a teaching-learning sequence (TLS) aimed to contextualize gravitational physics along the lines of the Einstein Telescope educational program in Sardinia devoted to upper secondary school students. We focused on the role of debates and controversy in the evolution of science, proposing science-reflexive meta-discourses to present physics as a unified knowledge textbook. We discuss our design and present results by analyzing students' semiotic registers to recap their learning during the activity. Finally, we discuss the potentiality of our TLS in orientating students towards STEM.

1. – Introduction

Since the earliest human inquiries into the cosmos, the desire to understand the fundamental interactions shaping the universe —particularly gravity— has been a driving force. The advent of general relativity and the rise of modern cosmology profoundly transformed this understanding, revolutionizing conceptions of space, time, and gravitation [1]. Although various cultures historically sought to explain the universe, only with general relativity and the discovery of gravitational waves did a deeper understanding of its structure and dynamics emerge [2-7]. These theories, describing how mass influences spacetime, have significantly expanded our cosmic view. Gravitational waves, in particular, provide a new observational window, enabling the study of phenomena such as black hole mergers [8]. Future detectors like the Einstein Telescope (ET) aim to extend observational capabilities across the entire universe, increasing sensitivity by an order of magnitude compared to previous generations [9-11].

The historical development of these theories offers valuable insights into the scientific process, making it an ideal focus for educational initiatives targeting high school students [12, 13]. Engaging with this evolution helps students grasp both scientific concepts and the dynamic nature of knowledge construction [14-18]. However, persistent misconceptions —such as interpreting the “Big Bang” as a classical explosion— often hinder understanding. These misunderstandings, frequently rooted in intuitive but incorrect metaphorical visualizations, obscure the underlying physics [19, 20]. Addressing such misconceptions is essential, as it encourages critical engagement with both scientific content and its historical development [14, 15]. Given the pivotal role of metaphors in learning —shaping how problems are framed and solutions conceived— promoting critical reflection on metaphorical language is fundamental to conceptual understanding [20-22].

Constructing meaning in physics also requires navigating diverse semiotic registers, such as natural language, algebraic expressions, diagrams, and vectorial representations [23-25]. Registers can vary depending on context, audience, purpose, and social setting. Natural language plays a central role, particularly when transitioning between semiotic registers —a challenge that becomes especially prominent in complex domains like quantum mechanics [26]. Duval’s work emphasizes the need to integrate multiple registers to support meaning-making in science education [25].

Guiding students toward a proper understanding of conceptual issues related to contemporary physics is essential. Research in physics education further emphasizes the importance of presenting scientific developments within their historical context [17, 27, 28]. Viewing scientific revolutions as gradual processes, rather than abrupt events triggered by isolated “genius” ideas, provides students with a more accurate perspective on scientific progress [15]. As Heilbron observed (see [15], p. 8), “The Scientific Revolution is a metaphor as well as a shorthand for particular developments within a historical period. The metaphor has given rise to much debate between those who regard these developments primarily as an abrupt transformation and those who view them as a continuity of pace and content.” Thus, the notion of the “Scientific Revolution” itself should be understood as a metaphor reflecting complex historical developments rather than a single transformative moment.

Embedding scientific content within its historical and epistemological contexts enhances students’ curiosity, combats misconceptions, and fosters deeper conceptual understanding [16-20, 29]. This approach has been shown to strengthen scientific argumentation skills, metacognition, and students’ attitudes toward science, ultimately enriching their learning experiences and promoting a more nuanced view of the nature of scientific inquiry [13, 16, 29].

The aim of this study was to design a teaching-learning sequence focused on the historical and epistemological aspects of contemporary physics —particularly general relativity, and modern cosmology— intended for high school students and suitable for implementation in non-formal contexts, such as educational outreach programs or curricular in-class activities. The goal was to help them better understand these complex concepts, addressing the following research question:

RQ1: How can we design a teaching/learning sequence that integrates the historical and epistemological reconstruction of cosmology (relativistic astrophysics) with modern research in physics in a non-formal learning context?

RQ2: How can the learning process of students be monitored during such a learning activity?

RQ3: What conceptual categories do students develop during the process of learning physics in a non-formal context?

2. – Theoretical framework

In recent years, there has been a growing global interest in diversifying scientific curricula in upper secondary school to enhance students' learning experiences, particularly in physics. This shift allows a broader range of topics to be explored, directly addressing learners' interests. In particular, non-formal education appears to hold great potential in this regard, as it provides opportunities for educational experimentation aimed at promoting the learning of physics in schools, motivating, intriguing, and capturing the attention of students, teachers, and the wider public [13, 30]. Non-formal education occurs outside traditional schooling but within an institutional framework, such as cultural centers or extracurricular activities, and is often delivered by specialists. It fosters interdisciplinary skills, flexibility, and active learning, providing opportunities for personalized learning strategies based on students' interests. This approach complements formal education by promoting holistic learning, offering avenues for self-assessment, and increasing student engagement [31, 32].

Teaching/learning sequences (TLS) can be used to introduce students also to contemporary physics in non-formal contexts. Even if they have been primarily used in formal contexts, TLS are a powerful and versatile tool to be adapted to many educational settings. Indeed, they consist in structured instructional activities designed to guide students through the exploration and understanding of specific scientific concepts. These sequences incorporate progressive learning steps that include conceptual development, student engagement, and formative assessment, all aimed at promoting deep understanding and meaningful learning. TLS ensure the sequentiality and coherence of contents, emphasize key concepts, and incorporate active, playful, and collaborative methodologies [33-40].

The TLS designed for this study is based on the principles of the Model of Educational Reconstruction (MER) and Design-Based Research (DBR) [41-46]. Together, these frameworks offer a robust foundation for developing, testing, and refining educational content and pedagogical strategies. MER, in particular, guided the selection and structuring of scientific content, emphasizing epistemological reflection and the integration of empirical research on teaching and learning. This approach ensured that the instructional materials remained scientifically accurate while being adapted for educational relevance, especially in fields like cosmology and relativistic astrophysics, which are not yet fully integrated into mainstream school curricula [16]. In parallel, DBR provided a methodological framework for developing effective teaching practices through iterative cycles of design, implementation, and refinement in collaboration with practitioners. Its focus on addressing real-world educational challenges made it an ideal tool for tailoring learning environments that foster active student engagement.

In this study, the design of the learning environment was central to the research process. Initial design hypotheses, drawn from the structured content analysis, guided the development of learning activities. These hypotheses were tested in classroom settings, allowing iterative improvements and the formulation of research-based design principles. To create an effective and motivating learning environment, we emphasized practices that encourage active student participation, such as collaborative work, inquiry-based learning, and play-based activities. In particular, Inquiry-Based Science Education (IBSE) provided a strong pedagogical foundation, promoting hands-on and minds-on activities that allow students to take an active role in constructing their understanding [47].

Following research on the role of language in the development of abstract thought [18, 24-26], our instructional design incorporated discussion, writing tasks, and verbal reasoning as key cognitive tools. Learning and conceptual development in general relativity and cosmology were conceptualized as processes rooted in social interaction, involving not only peers and instructors but also engagement with the physical and technological environment [13, 16, 18, 30]. Knowledge construction was thus approached as a collaborative endeavor. In this context, our strategy for fostering a deep understanding of complex relativistic concepts was based on designing activities that engage students in "playing physics" through the use of different cognitive tasks and (both semiotic and linguistic) registers —such as speaking, writing, and thinking— focused on the conceptual dimensions of physics.

3. – Methodology

The project involved four high schools in Sardinia (Italy) and targeted students in the final three years of study (ages 16 to 19). It was carried out as part of the Italian *Piano Nazionale di Ripresa e Resilienza* (PNRR, National Recovery and Resilience Plan) initiative "Le frontiere della fisica" ("The Frontiers of Physics"), organized by the Department of Physics at the University of Cagliari. A total of 119 students participated (68 males and 51 females). Regarding school types, 1 student was enrolled in an arts high school (*liceo artistico*), 12 in applied sciences high school (*liceo delle scienze applicate*), and 106 in scientific high school (*liceo scientifico*). As for their grade levels, 45 students were in the third year (ages 16–17), 58 in the fourth year (ages 17–18), and 16 in the fifth year (ages 18–19).

For each participating school, the activity consisted of a single three-hour session, scheduled between January and February 2024. Each session included 150 minutes of content delivery, followed by 30 minutes of group work ("playtime") during which students collaborated in small groups (36 groups in total, composed of two, three, or four students each). This structure was designed to foster collaborative learning and active engagement.

Content was delivered through a combination of theoretical explanations and experimental activities, with adaptations based on the students' academic level (*e.g.*, more detailed discussions for final-year students). The topics and their conceptualization were introduced from a historical perspective, tracing the evolution of ideas and discoveries over time. The sequence covered Aristotle's theory of motion and cosmology; Galileo's and Newton's physics of motion; pre-relativistic cosmological models; Einstein's theory of General Relativity and its phenomenology; modern cosmology; gravitational waves; and the Einstein Telescope. For each topic, emphasis was placed on conceptual challenges and the paradigm shifts that were necessary to achieve a more comprehensive understanding of physical phenomena [14, 15].

To foster an inquiry-based learning process, simple experiments in classical mechanics were integrated into the sessions. Mathematical formalism related to contemporary gravitational physics was intentionally avoided; instead, the focus was on phenomenology, promoting abstract and conceptual visualization through storytelling, videos, and embodied experiences that actively engaged students in narrating and internalizing the content. Further details are provided in table I.

The design of the TLS began with a thorough analysis of the scientific content associated with these topics, which was then structured within a cooperative learning framework. This approach allowed for iterative refinement to ensure that the material remained scientifically rigorous yet accessible to students [48]. Particular emphasis was placed not only on maintaining conceptual accuracy but also on presenting the content

Table I. – *The table shows the topics and the structure of our TLS.*

Duration	Topics and concepts	Educational tools
90 minutes	Motion of bodies • Aristotelian motion (natural motion, "*horror vacui*") • Newtonian dynamics (force, acceleration, equilibrium, $F = ma$, gravitational force) • Einstein's gravity (equivalence principle, general covariance, spacetime and matter)	• Experiments on the fall of heavy bodies (*e.g.*, common objects, balls) to work on the concept of force and related conceptions • Educational videos and animations on free fall, motion on curved spaces • Debates, questions, and answers.
60 minutes	The universe • Aristotle's cosmology • Pre-relativistic universe • Relativistic astrophysics (cosmological model, Big Bang metaphor, the observable universe, the dark universe, GR tests, gravitational waves, interferometers and the Einstein Telescope)	• "Embodied" experience on gravitational lensing • Debates, questions, and answers
30 minutes	Formative evaluation	Wording, and crossroads

in ways that would enhance understanding and foster engagement. The topics covered are outlined in table I.

Following the implementation of the teaching strategies, their effectiveness was evaluated through formative assessments and qualitative feedback. The assessment process consisted of two phases —*wording* and *crossroads*— as outlined in table II. The *wording* phase engaged students in reflecting on key conceptual issues addressed during the activity, encouraging them to articulate and define concepts through both speaking and writing based on their learning process. The *crossroads* phase actively involved students in the activity, fostering motivation and deeper engagement with the learning content.

Integrating both talk and writing in the development of students' scientific reasoning and knowledge construction has been shown to be effective across multiple educational dimensions [49]. In particular, the simultaneous use of talk and writing within collaborative learning contexts supports deeper conceptual understanding and enhances critical reasoning skills. Furthermore, linking distinct cognitive functions to different communicative patterns promotes higher-order processes such as the integration of perspectives, critical evaluation, and increased audience awareness. Overall, combining talk and writing expanded the cognitive scope of students' argumentation, strengthening both the construction and critique of scientific knowledge.

Our primary investigation focused on analyzing the definitions produced by students during the crossroads activity. Inspired by Michelini [50], we conducted a qualitative analysis and organized the definitions into four conceptual categories. Two adaptations were made to tailor the categorization to our research context: the category "Quoted Statements" was revised to "Scientific Definitions," and "Recollection of Experiences" was modified to "Recollection of Learning Experiences" to better reflect the background of our high school student sample.

TABLE II. – *Structure of the formative evaluation tasks.*

Task	Description	Teaching/learning benefits
Wording ("Today's words")	Final summary activity to keep track of students' reconstruction of all the contents discussed during the meeting.	• Promoting instructor-student and student-student interactions • Promoting creativity: students explain why they chose a certain word; in what context it was used and why it summarizes a certain content covered • Construction of conceptual maps —creation of nodes and mental associations between learning contents and real-world phenomena
Crossroads ("Revolutionary crossroads")	The students, divided into groups, choose one or more words and give a definition. The words and definitions are collected by the teacher who presents the individual definitions to the class through the crossword game. The group that guesses the most words (excluding those they wrote) wins.	• Promoting cooperative learning and inquiry through a minds-on activity • Possibility for the instructor to uncover any erroneous conceptions and investigate whether they are real or dictated by the extreme synthesis imposed by the game. • Promoting the ability to create a link between physical knowledge and natural language.

The first category, *Declarative Statements*, includes static, instructional definitions that present terms in a straightforward and descriptive manner. The second category, *Scientific Definitions*, consists of textbook-style definitions or those provided by students that accurately reflect the associated scientific content. The third category, *Recollection of (Learning) Experiences*, encompasses definitions based on prior knowledge or information acquired during the activity. Finally, the *Interpretative Statements* category captures definitions that reflect students' personal interpretations of the physical meaning of the term.

To investigate the linguistic and semiotic registers, as well as the lexical and semantic nuances in students' responses, each definition was assigned both a primary and a secondary category. For example, a definition classified as a primary *Scientific Definition* and secondary *Declarative Statement* exhibits the features of a scientific explanation but is presented in the form of a simple, instructional statement. Conversely, a definition assigned a primary *Declarative Statement* and secondary *Scientific Definition* resembles a scientific explanation but lacks the essential features required for full scientific accuracy. This dual categorization allowed us to more precisely trace students' reasoning processes and linguistic choices, see table III. This dual categorization not only improved the precision of classification but also allowed for a deeper exploration of students' reasoning processes. It enabled us to trace the evolution of their conceptual understanding and to identify potential misconceptions or misunderstandings, distinguishing whether they originated from prior knowledge, were developed during the activity, or stemmed from linguistic ambiguities.

TABLE III. – *The distribution of collected definitions according to each identified macro-topic is presented. The table also shows the assigned primary (in bold) and secondary (in regular font) categories, along with comments by the authors. The legend is as follows: declarative statements (DS), scientific definitions (SD), recollections of learning experiences (RE), and interpretative statements (IS).*

			Category				
Topic	**Word**	**Definition**	**DS**	**SD**	**RE**	**IS**	**Comments**
Gravitational interaction	Gravity	Force perpendicular to the plane	**X**		X		Incomplete, Classical Gravity
		Curvature of space related to mass	X	**X**			Einstein's gravity
		That which prevents bodies from floating. Initially, it was thought that it was based on the similarity between bodies — like attracts like — but thanks to Newton, we discovered that it acts on every body and that objects do not fall depending on the height from which they fall, and that the trajectory varies.			X	**X**	Conceptually wrong, incomplete
		Phenomenon caused by the curvature of the space-time fabric due to very large masses. Perceived by us as the attraction between two bodies.		**X**		X	Einstein's gravity
		Attractive force between two masses	X	**X**			Classical gravity
	Time	Relative unit of measurement, dependent on space and gravity (if we are near a massive gravitational center, "time" passes more slowly), excluding quantum time and thermal time.		X		**X**	Time according to General Relativity; relativistic time
		It can be considered as a dimension in which events follow one another, and it is also relative, as it changes based on speed and gravity.		X		**X**	Time according to General Relativity; relativistic time; not completely right (logic reversed: velocity, curvature, acceleration)
		Near a black hole, it flows more slowly.	**X**		X		Time phenomenology according to General Relativity
		Drawing: light cone.		X	**X**		Time as causal strucutre of spacetime in Minkowski; special relativity
		It flows incessantly and cannot go backward (it is relative).	**X**			X	Physical/Philosophical interpretation
Mechanics	Acceleration	Variation of velocity over a given time interval. Its formula is (Δv)/(Δt)		**X**	X		Textbook definition
		Relationship between speed and time.		**X**	X		Textbook definition
		Ratio between the distance traveled and the time taken.		**X**	X		Textbook definition
		Ratio between the velocity of the body considered and the time interval.		**X**	X		Textbook definition
	Velocity	Ratio between the distance traveled and the time taken to travel it.		**X**	X		Textbook definition
		Ratio between the distance traveled and the time taken to travel it.		**X**	X		Textbook definition
	Inertia	Resistance of a body to what is caused by a force.		**X**	X		Textbook definition
	Friction	Force that opposes the motion of a body.		**X**	X		Textbook definition
Astrophysics	Neutron stars	One of the possible outcomes of the death of a star, which varies depending on the mass of the original nebula.		X		**X**	Wording, quite correct
	Star	Celestial bodies composed of hot gas and plasma, compacted by gravity. Within the plasma are scattered particles; unlike planets, they shine with their own light.		**X**	X		Quite complete

TABLE III. – *Continued.*

		Celestial bodies that emit their own light, within which thermonuclear processes occur. They are made of gas and plasma.		**X**	X		Quite complete
	Black hole	Distortion of space at the center of our galaxy.		X		**X**	Statement according to General Relativity but incomplete (space -> spacetime) and too general
	Black hole	Celestial body with extremely strong gravity from which nothing can escape (including light); caused by the explosion of multiple masses.		X		**X**	Quite complete; wrong quoting
	Dark matter	Particles not yet discovered or observed.	X			**X**	Incomplete definition
	Orbit	Elliptical trajectory traveled by planets.		X	**X**		Newtonian gravity
		The more or less circular path followed by a body due to gravity.		X	**X**		Newtonian gravity
Philosophical foundations	Curiosity	Invisible force that drives humans toward the unknown and the truth.		X		**X**	Free interpretation
		Animates research.	**X**			X	Free interpretation
		Desire for knowledge.	**X**			X	Free interpretation
		Nourishes the human mind.	**X**			X	Free interpretation
	Nature	All the matter that surrounds us (forests, animals, etc.).	**X**		X		Content-poor definition
Cosmology	Universe	Infinite space in continuous expansion.	**X**			X	Space as spacetime; cosmological statement
		Collection of celestial bodies surrounding the Earth.	**X**			X	Anthropocentric
	Cosmos	Collection of celestial bodies in the universe and the universe itself.	X	**X**			Tautology
	Big bang	Great primordial explosion.	**X**			X	Misconception
Electromagnetism	Electromagnetic waves	Transfer of energy through fields that propagate perpendicular to each other.		**X**	X		Quite scientific
		We see only a small portion, but it is part of a much larger whole that we cannot perceive (electromagnetic waves).			X	**X**	Not precise definition
	Light	It is a wave that propagates through the vacuum, of which we can see only a small spectrum.		**X**	X		Incomplete wording ("small spectrum"); incomplete definition
Physicists	Galileo Galilei	He had a dream: to write the mathematics of the universe. His thinking was based on sensible experiences. He built upon the studies of a great philosopher.		X		**X**	Learning experience based on the in-class historical reconstruction
	Aristotle	His conception remained dominant for 2000 years.	X		**X**		Learning experience based on the in-class historical reconstruction
Mathematical foundations	Formula	Equation that allows the calculation of a value or measurement.	**X**			X	Not completely right, but quite complete

Moreover, this approach recognized the hybrid nature of many definitions, which often exhibited features spanning multiple categories and could not be neatly classified into a single one. Overall, the dual categorization provided a more nuanced and comprehensive perspective on how students construct and articulate scientific knowledge.

4. – Results and discussion

Regarding the "*wording*" phase, the list of words and definitions chosen by the students is presented in table III and fig. 1. Figures 2 and 3 display the overall distribution of topics and the number of definitions associated with each topic. Results concern-

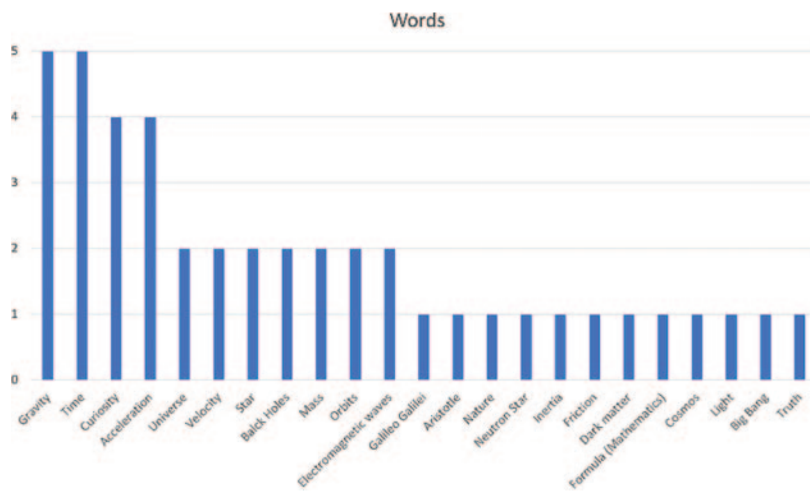

Fig. 1. – Words listed by students and corresponding frequency (on the y-axis).

ing the categorization of students' definitions under primary and secondary conceptual categorization are summarized in tables III and IV.

The analysis of student definitions in physics education revealed valuable insights. Specifically, in 17.1% of cases, students who provided a definition in the form of a static statement based their response on a free interpretation of the term. In 29.3% of cases, students who proposed a scientific definition grounded their responses in knowledge acquired either during the activity (which focused on gravitational physics, astrophysics, and the philosophical aspects of physics) or from prior schooling in classical physics. An example of this was a student who defined acceleration as "*the change in velocity over a given period of time*." Moreover, in 19.5% of cases, students offering a free definition provided an interpretation that was consistent with the scientific definition of the term. For instance, one student defined time as "*a relative unit of measure, dependent on space and gravity, where time passes more slowly near a gravitational center*."

Concerning the distribution of definition within primary and secondary categories, we observed a prevalence of definitions related to the topic "Mechanics", see table IV. This trend reflects the influence of students' prior school learning in classical physics, particularly in mechanics. Although the activity addressed the concept of acceleration within

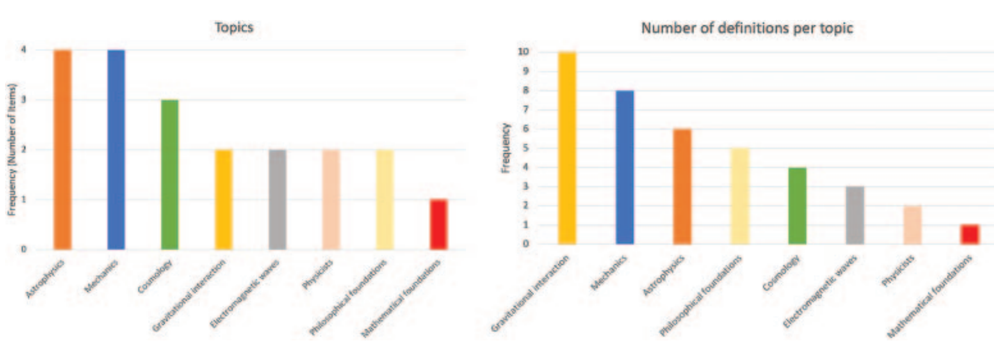

Fig. 2. – Overall topics (on the left) and number of definitions per topic given by students (on the right).

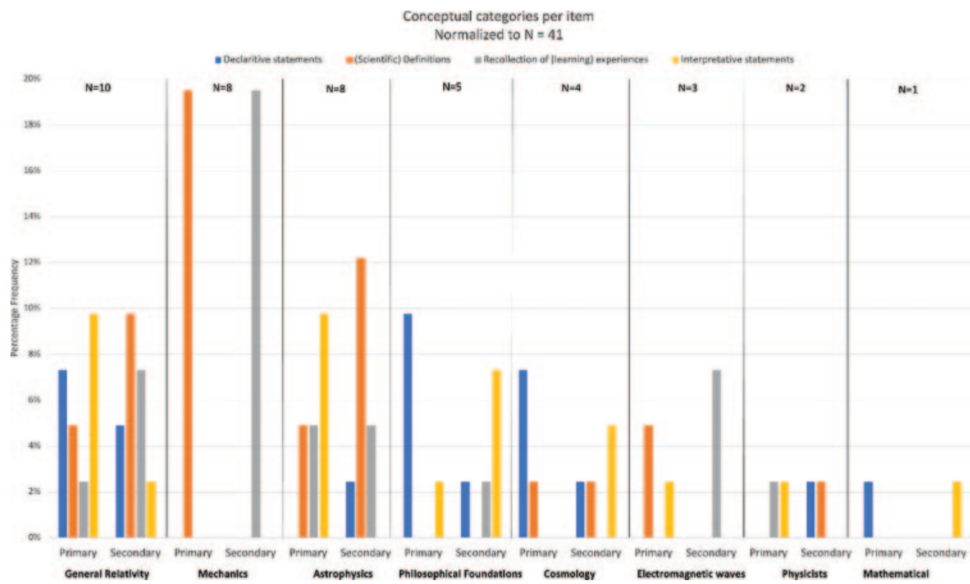

Fig. 3. – Conceptual categories for each of the topics chosen by students. Each group of statements is normalized to the total number of definitions ($n = 41$) collected.

the framework of Newtonian gravity and general relativity, and explored its historical evolution from Aristotle to Einstein, students predominantly recalled and employed the standard textbook definition rooted in classical mechanics. In this sense, the observed prevalence constitutes a bias, as it reveals a reliance on pre-existing knowledge acquired during traditional schooling rather than the new conceptual perspectives introduced during the activity. Excluding this effect, the corresponding percentage dropped to 9.8%.

When defining concepts like gravity and the Big Bang, students often relied on textbook or online sources, resulting in attempting to give a scientific definition as a primary semantic and linguistic category, but resulting in creative reconstructions of terms (“*In-*

Table IV. – *The distribution of definitions according to primary and secondary categories. Numbers represent the percentage of statements fitting each specific category. The highest percentages are in bold.*

		Secondary category			
		Declarative Statements	*Scientific Definitions*	*Recollection of (Learning) Experiences*	*Interpretative Statements*
Primary category	*Declarative Statements*	–	2.4	7.3	**17.1**
	(Scientific) Definitions	7.3	–	**29.3**	0
	Recollection of (Learning) Experiences	2.4	7.3	–	0
	Interpretative Statements	2.4	**19.5**	4.9	–

terpretative Statements"). Some referenced historical figures like Aristotle and Galileo, indicating that students drew heavily from prior knowledge. Misconceptions were common, particularly regarding gravity, with one group defining it as "*what keeps bodies from floating*," and another describing it as a force perpendicular to the plane. The Big Bang was often referred to as a "*primordial big explosion*," a typical misconception in cosmology [20], going under the category of statements that are rooted in students' interpretation of phenomena. Students frequently used metaphors like "*time is fluid"* to describe abstract concepts. Tautological definitions and linguistic challenges also emerged, reflecting difficulties in articulating scientific ideas.

The categorization model from [50] closely aligns with our findings. However, assigning both a primary and a secondary conceptual category to each student definition was essential for gaining a deeper insight into students' learning processes and reasoning patterns. This approach made it possible to capture the hybrid nature of their thinking, where definitions often blended elements of formal scientific knowledge, recollections of prior learning experiences, and personal interpretations. For instance, in defining gravity, some students employed scientific language, referring to it as a "*force perpendicular to the plane*," while others adopted a more interpretative and metaphorical register, describing it as "*the invisible force that moves humans toward the unknown and truth."* Similarly, for time, definitions ranged from precise scientific formulations —such as "*relative unit of measurement dependent on space and gravity"*— to more experiential reflections, like "*it flows incessantly and cannot go backward*."

The dual categorization allowed us to trace how students navigated among different semiotic registers, particularly shifting between formal scientific language, everyday speech, and metaphorical descriptions. In several cases, students combined scientific elements (*e.g.*, describing gravity as the "*curvature of space related to mass"*) with intuitive notions (*e.g.*, representing space simply as "*infinite and in continuous expansion*" without reference to a specific cosmological model), revealing an ongoing negotiation between acquired scientific models and intuitive or imaginative worldviews. This strategy provided a more nuanced understanding of students' semiotic resources and conceptual associations. It highlighted not only the extent of their assimilation of disciplinary language but also exposed areas where misconceptions or linguistic ambiguities could emerge. Moreover, it offered valuable insight into how students use language to make sense of complex physics concepts, suggesting new opportunities for instructional interventions aimed at gradually strengthening the alignment between intuitive reasoning and scientific formalism.

Our findings also suggest the need for scientific literacy in school concerning contemporary physics to prevent the structuring of misunderstandings or misconceptions in students' conceptual understanding. Non-formal and informal learning activities, also connected to suitably designed outreach programs according to our framework could help in addressing this educational issue [13,30]. We also noticed that students in lower grades, particularly third-year students, provided definitions more aligned with contemporary physics, suggesting they were more open to modern scientific ideas. Some students even remarked, "*But this is philosophy!"* indicating a perceived overlap between physics and philosophy, which invites further reflection on the boundaries between the two disciplines from historical, epistemological, and educational perspectives [17, 27-29].

5. – Conclusion

This paper presents a TLS designed to introduce high school students to contemporary physics topics in non-formal learning contexts. Grounded in the MER and DBR frameworks, the TLS contextualizes physics through its historical development, highlighting key controversies, challenges, and open questions while fostering curiosity and cooperative learning (RQ1).

Our findings suggest that formative assessment tools, such as game-based approaches, are effective for tracking students' learning processes and are well-suited for non-formal educational contexts. Formative evaluations provided valuable insights into students' learning trajectories and the influence of teaching methods (RQ2). Classroom discussions indicated strong engagement, with students particularly appreciating the interdisciplinary nature of the activity and expressing interest in similar initiatives for future integration into curricula.

The analysis of language and semiotic registers revealed reasoning patterns, conceptual categorizations, and potential misconceptions (RQ3). During the "*wording*" phase, students' use of metaphors, analogies, and linguistic limitations in describing physical phenomena was examined. Categorizing word choices into primary and secondary categories offered deeper insight into their conceptual development and ability to articulate physics concepts more precisely.

In conclusion, the TLS and interdisciplinary approach proved valuable for engaging students in STEM education and promoting academic aspirations. Future research will involve a larger-scale quantitative study to further assess students' conceptions of contemporary physics and a targeted questionnaire to evaluate the activity's impact on motivation and engagement.

REFERENCES

[1] Deruelle N. and Uzan J. P., *Relativity in Modern Physics* (Oxford University Press) 2018.
[2] Kragh H. S., *Conceptions of Cosmos: From Myths to the Accelerating Universe —A History of cosmology* (Oxford University Press) 2007.
[3] Blum R., Lalli R. and Renn J., *Isis*, **106** (2015) 598.
[4] Goenner H., *Gen. Relativ. Gravit.*, **49** (2017) 42.
[5] Longair M. S., *A brief history of cosmology*, in *Measuring and Modeling the Universe*, Vol. **2**, edited by Freedman W. L. (Cambridge University Press) 2004.
[6] Hughes D. W. and de Grijs R., *Commun. Astron. Public J.*, **1** (2007) 11.
[7] Vitale S., *Science*, **372** (2021) abc7397.
[8] Abbott B. P. *et al.*, *Phys. Rev. Lett.*, **116** (2016) 061102.
[9] Maggiore M. *et al.*, *J. Cosmol. Astropart. Phys.*, **03** (2020) 050.
[10] Branchesi M. *et al.*, *J. Cosmol. Astropart. Phys.*, **07** (2023) 068.
[11] Punturo M. *et al.*, *Class. Quantum Grav.*, **27** (2010) 194002.
[12] Tuveri M. and Steri A., *Phys. Educ.*, **60** (2025) 015002.
[13] Tuveri M., Steri A. and Fadda D., *Phys. Educ.*, **59** (2024) 045031.
[14] Morganti M., *Filosofia della fisica. Un'introduzione* (Carocci Editore) 2016.
[15] Heilbron J. L., *The History of Physics: A Very Short Introduction* (Oxford University Press) 2018.
[16] Kersting M., Henriksen E. K., Vetleseter Bøe M. and Angell C., *Phys. Rev. Phys. Educ. Res.*, **14** (2018) 010130.
[17] Levrini O., *Sci. Educ.*, **11** (2002) 263.
[18] Kersting M., *Using the language of gravity to teach about space, time, and matter in general relativity*, in *Teaching Einsteinian Physics in Schools*, 1st edition (Routledge) 2021.
[19] Kragh H., *Astron. Geophys.*, **54** (2013) 28.
[20] Kragh H., *Sci. Educ.*, **20** (2011) 343.
[21] Corni F., *Phys. Teach. Educ.*, **3** (2023) 3.

[22] Kokkotas P. *et al.*, *Nonlinear Anal.: Theory, Methods Appl.*, **30** (1997) 2113.
[23] Kramar N. *et al.*, *Amazon. Investiga*, **10** (2021) 92.
[24] Tiberghien A. *et al.*, *Science and technology education at crossroads: Meeting the challenges of the 21st century*, paper presented at the *Second EDIFE Conference and the Second IOSTE Symposium in Southern Europe* (2005).
[25] Duval R., *Semiosis et pensée humaine: Registres sémiotiques et apprentissages intellectuels* (Peter Lang) 1995.
[26] Brookes D. T. and Etkina E., *Phys. Rev. Phys. Educ. Res.*, **8** (2012) 010105.
[27] Fouad K. E., Masters H. and Akerson V. L., *Sci. Educ.*, **24** (2015) 1103.
[28] La Rana A., *Gravitational Waves: An Historical Perspective*, in *New Challenges and Opportunities in Physics Education. Challenges in Physics Education*, edited by Streit-Bianchi M., Michelini M., Bonivento W., Tuveri M. (Springer, Cham) 2023.
[29] Gooday G. *et al.*, *Isis*, **99** (2008) 322.
[30] Tuveri M. *et al.*, *Nuovo Cimento C*, **46** (2023) 210.
[31] Gorghiu L. M. *et al.*, *The role of non-formal activities on familiarizing students with cutting-edge science topics*, in *Proceedings of the Education, Reflection, Development Conference* (Future Academy) 2016.
[32] Eshach H., *J. Sci. Educ. Technol.*, **16** (2007) 171.
[33] Komorek M. and Duit R., *Int. J. Sci. Educ.*, **26** (2004) 619.
[34] Lijnse P., *Int. J. Sci. Educ.*, **26** (2004) 537.
[35] Battaglia O. R., Gallitto A. A., Termini G. and Fazio C., *Educ. Sci.*, **13** (2023) 425.
[36] Tiberghien A., Vince J. and Gaidioz P., *Int. J. Sci. Educ.*, **31** (2009) 2275.
[37] Buty C., Tiberghien A. and Le Maréchal J.-F., *Int. J. Sci. Educ.*, **26** (2004) 579.
[38] Marzari A., Di Mauro M., Rosi T., Onorato P. and Malgieri M., *Educ. Sci.*, **13** (2023) 712.
[39] Tiberghien A., Buty C. and Le Maréchal J.-F., *Physics teaching sequences and students' learning*, manuscript for the *Proceedings of the 2nd Conference of EDIFE and the 2nd IOSTE Symposium in Southern Europe, Kalamata, Greece, March 18–20 2024*.
[40] Méheut M. and Psillos D., *Int. J. Sci. Educ.*, **26** (2004) 515.
[41] Duit R., Gropengiesser H., Kattmann U., Komorek M. and Parchmann I., *The model of educational reconstruction —a framework for improving teaching and learning science*, in *Science Education Research and Practice in Europe: Retrospective and Prospective*, edited by Jorde D. and Dillon J. (Sense Publishers, Rotterdam), 2012 pp. 13–37.
[42] Anderson T. and Shattuck J., *Educ. Res.*, **41** (2012) 16.
[43] Barab S. and Squire K., *J. Learn. Sci.*, **13** (2004) 1.
[44] Brown A. L., *J. Learn. Sci.*, **2** (1992) 141.
[45] Psillos D. and Kariotoglou P., *Teaching and Learning in the Science Laboratory* (Springer) 2002.
[46] Leach J. and Scott P., *Stud. Sci. Educ.*, **38** (2002) 115.
[47] Pedaste M., Mäeots M., Siiman L. A., de Jong T., van Riesen S. A. N., Kamp E. T., Manoli C. C., Zacharia Z. C. and Tsourlidaki E., *Educ. Res. Rev.*, **14** (2015) 47.
[48] Tuveri M., Steri A. and Fanti V., *Designing a teaching/learning sequence to train in-service lower secondary school teachers in physics*, in *Connecting Physics Education Research and Practice*, edited by Michelini M., Testa I., Esposito S., *Challenges in Physics Education* (Springer) 2025.
[49] Chen Y. C., Park S. and Hand B., *Cogn. Instr.*, **34** (2016) 100.
[50] Michelini M., *Research-based MEDS model to build prospective primary teachers' professional competence in physics education*, in *Frontiers of Fundamental Physics FFP16*, edited by Aydiner E., Sidharth B. G., Michelini M. and Corda C., Vol. **392** (Springer) 2024.