Part 5 / Strand 5

Nature Of Science: History, Philosophy And Sociology Of Science

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Nature of science and its history, philosophy, sociology and epistemology for teaching/learning of science. Includes the significance of models and modelling for science education as reflected in the particular importance attached to the use of metaphors, analogy, modelling, argumentation, explanation, visualisation, simulations, animations and gamifications in science.

Sub-themes:

1) Philosophical Foundations of Science Education
2) The Role of History & Philosophy of Science in Science Education
3) Nature of Science and Epistemic Practices
4) Sociological Perspectives on Science Education

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Strand 5: Nature Of Science (NoS): History, Philosophy And Sociology Of Science

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The strand “Nature of Science (NoS): History, Philosophy and Sociology of Science” explores science as a dynamic human endeavour shaped by historical, philosophical, sociological, and epistemological dimensions. It emphasizes that scientific knowledge develops over time through social and cultural contexts, influenced by human reasoning and interpretation, and highlights how scientific understanding is constructed and validated within the scientific community.

The contributions in this chapter examine developments in science education research with a particular focus on pre-service teachers’ and students’ understandings of the Nature of Science (NOS) from a broader epistemic perspective, and more specifically on understandings of the Nature of Scientific Knowledge (NOSK) and the Nature of Scientific Inquiry (NOSI). Across the studies, these understandings are explored in different ways: some investigate existing levels of conceptual understanding, while others design and implement instructional interventions aimed at enhancing deeper insight. Some contributions focus on specific dimensions of NOS and NOSI, including the nature of scientific measurement and scientific reasoning. In addition, some contributions draw on the history of science as a pedagogical tool to strengthen understanding of NOS and NOSK, or to promote scientific literacy with an emphasis on social transformation. Overall, the chapter highlights a range of approaches to enhancing how learners and future educators engage with and understand the nature and practices of science.

This chapter aligns with the “Nature of Science (NoS): History, Philosophy and Sociology of Science” strand, contributing to a well-established area of science education research concerned with how learners and teachers understand the epistemological foundations and functions of science. The work aligns with longstanding efforts in science education to move toward developing a deeper understanding of science as a way of knowing, investigating, and explaining the natural world. Epistemically and as a human endeavour, science functions to generate, evaluate, justify, and refine explanations of natural phenomena. Simultaneously, scientific knowledge and practices are recognized as socially and culturally embedded, shaped by prevailing theories and cultural contexts, as well as the values, priorities, and needs of society.

Insights Into Physics Students' Lesson Plans On The Nature Of Scientific Knowledge

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A program, based on the Lederman's model, was designed to familiarize physics students with the Nature of Scientific Knowledge (NOSK) aspects and its teaching. The program was implemented in Greece during the academic years 2023-24 and 2024-25 and included interactive lectures and workshops. Students' pre-instruction understanding was examined using the VNOS-D+ questionnaire, while their post-instruction integration of NOSK through the analysis of lesson plans. The lesson plans were evaluated for their incorporation of NOSK aspects using teaching approaches such as History of Science (HOS), Scientific Inquiry (SI), and Socio-scientific Issues (SSI). Findings indicate that prior to instruction, students mainly recognized the empirical and tentative nature of scientific knowledge, while other NOSK aspects were often understood in naïve or mixed ways. Analysis of students' lesson plans showed a strong preference for SI alone or in combination with HOS, with students most frequently selecting certain curriculum-related physics topics such as free fall. Although several NOSK aspects were included, the empirical, tentative, and creative dimensions were most successfully integrated. While NOSK was often addressed implicitly, approximately one-third of the students produced lesson plans that demonstrated explicit and reflective integration of NOSK. Overall, the findings suggest that even brief, structured NOSK-focused instruction can support pre-service physics students' initial engagement with NOSK, while highlighting the need for sustained involvement to support effective classroom implementation.

Keywords: Nature of Science, Pre-service Teacher Education, Undergraduate Level

Introduction

Research in Nature of Science (NOS) is fundamental in Science Education, since it is inherent in science and its practices (Lederman et al., 2014). It is also connected to scientific literacy (Lederman et al., 2024) and, regarding science education, the views that students and educators have on scientific research and epistemology (McComas, 2015).

The necessity to integrate the nature of science at all levels of education has been highlighted by many researchers (Erduran & Dagher, 2014; Lederman et al., 2014; Matthews, 2015), and it is already embedded in science curricula in countries like the USA (NGSS, 2013) and New Zealand (https://newzealandcurriculum.tahurangi.education.govt.nz/nature-of-science/5637207725.p). Main reasons for it are enhancing students' active participation, better understanding of science and its epistemic views, comprehension of the differences between science and pseudoscience and the limitations of science as a human endeavour (McComas, 2017, Matthews, 2015).

Teachers and student teachers need to be trained to create effective lesson plans (Mesci & Schwartz, 2017). Teacher training in nature of science is still a matter of research (e.g. Kara & Aslan, 2025; Beeghly, Gao & Kruse, 2025; Sen & Kaplan, 2025; Bugingo et al, 2024) and it seems there is a lot to add in the literature. Towards this direction, the present work focuses on Greek physics students and the results of their training through the analysis of the lesson plans they delivered. In this way, the study aims to contribute empirical evidence to the existing literature by enlightening how physics students engage with the Nature of Science within a traditionally content-focused educational context.

Theoretical Background

Even though researchers agree on the importance of teaching NOS, they don't agree on a widely approved definition and the aspects it consists of (Kampourakis, 2016). There are two main models, the Consensus Model (Lederman et al., 2014; McComas, 2015) and the Family Resemblance Approach (Erduran & Dagher, 2014). Each model has its own advantages and disadvantages, and there is plenty of ink spilled in favor and against each model (Kampourakis, 2016). However, all researchers agree that NOS instruction should be in an explicit and reflective approach, so that students understand it (Bell, 2008; Lederman et al., 2014).

As for Greece, research shows that NOS is not officially integrated in the science curriculum in secondary education, teachers usually do not include it in their instruction and, as a result, high school graduates usually have naïve views of its aspects (Koumara & Plakitsi, 2020). The Greek science curriculum focuses a lot on the scientific content, solving complex mathematical problems and little inquiry work in the science lab. Thus, it is reasonable that senior undergraduate students have limited knowledge of NOS aspects, which also might influence their future approach in teaching science (Abd-El-Khalick & Akerson, 2010).

The Lederman model separates NOS to the nature of Scientific Knowledge (NOSK) aspects and the nature of Scientific Inquiry (NOSI) ones (Lederman, 2019). The NOSK aspects are shown in Table 1.

Table 1. NOSK Aspects according to Lederman, 2019

Aspect	Description
A1	Scientific knowledge is empirical, based on our senses and extensions of them
A2	Scientific knowledge is inferential, observations and inferences are different
A3	Scientists' creativity and imagination are needed in all parts of scientific research
A4	Even though objectivity is the goal, subjectivity within scientists is inevitable, derived from scientists' personal beliefs, background knowledge, training, expectations, etc
A5	Scientific knowledge is durable but changes in the light of new evidence
A6	Scientific knowledge is culturally embedded; it affects and is affected by societal, economical, political and/or cultural characteristics of each geographical and political era
A7	Scientific Laws and Theories are different kinds of knowledge; Laws are structured mathematical relationships, whereas Theories provide a well-substantiated framework of why a phenomenon happens.

Taking these considerations into account, a program based on Lederman's model was designed to familiarize physics students with NOSK aspects and their teaching.

This model was selected because it offers a practical framework for educational contexts in which the science curriculum does not explicitly prioritize NOS. It is easier for teachers to comprehend and integrate into their teaching practices (Koumara, 2024), while also benefiting from established instruments to assess NOS knowledge, such as the VNOS-D+ questionnaire (Abd-El-Khalick, 2014).

Furthermore, given the focus of the present study on students' lesson plans, three instructional approaches for integrating NOSK were considered: History of Science (HOS), Scientific Inquiry (SI) and Socio-scientific Issues (SSI) (Koumara, 2024). Each of these approaches offers affordances and challenges for NOSK teaching, making it important for future teachers to be familiar with all of them when designing lesson plans. Examining how students select and implement these approaches provides valuable insight into their pedagogical reasoning and their understanding of NOSK integration in science teaching.

Research Questions

The present study was guided by the following research questions:

a) What views do students hold regarding aspects of the Nature of Scientific Knowledge (NOSK) prior to the instructional program, and how do these views change following the program?

b) Which teaching approaches do students adopt when designing lesson plans that aim to integrate NOSK aspects?

c) To what extent do students integrate NOSK aspects explicitly and reflectively in their lesson plans?

Together, these research questions address whether pre-service physics students are able to design effective lesson plans in which NOSK is incorporated as an explicit and reflective component of science teaching.

Methodology

The Participants And The Context

The sample of the study consisted of 64 students from the Physics Department of Aristotle University of Thessaloniki, Greece, who were in the process of obtaining their teaching certificate. As part of the coursework, they followed to obtain their teaching qualification, the students attended a 5-hour program focusing on the Nature of Scientific Knowledge (NOSK), which constitutes the focus of the present study. Thirty-one students attended the program during the academic year 2023-24 and thirty-three during the academic year 2024-25. Within this context, students participated in two interactive lectures and two workshops. The lectures focused on core aspects of NOSK and on instructional approaches for teaching NOSK through History of Science, Scientific Inquiry, and Socio-Scientific Issues. The workshops included the Signals from Space activity from Perimeter Institute and a black-box activity involving electric circuits (Koumara, Plakitsi & Lederman, 2022). Participants were provided with presentation files of the program and relevant articles on NOSK and its teaching. As part of the course requirements, students were asked to design and submit a 2000-word lesson plan that emphasised the explicit and reflective integration of NOSK aspects.

Data Collection And Analysis

Multiple sources of data were collected and analysed to address the research questions of the study. Prior to the beginning of the program, all participants completed the VNOS-D+ questionnaire within approximately 40 minutes. The questionnaire provided insights into students' initial views on aspects of the Nature of Scientific Knowledge (NOSK) and served as a pre-test.

Following the completion of the instructional activities of the program, students were given approximately one month to develop and submit a 2000-word lesson plan, which served as a post-test. Students were asked to design the lesson plan by explicitly and reflectively incorporating as many NOSK aspects as possible, providing insights into their newly acquired knowledge. They were free to select any topic from subjects taught in Greek Secondary Education that a science teacher may be assigned to (Physics, Chemistry, Biology, Geography). Each lesson plan was examined with regard to (a) the NOSK aspects addressed and (b) the extent to which these aspects were integrated explicitly and reflectively. In addition, students were asked to complete a table at the end of their lesson plan, describing how each NOSK aspect had been incorporated. This information was analysed in conjunction with the lesson plan content in order to assess students' understanding of each NOSK aspect.

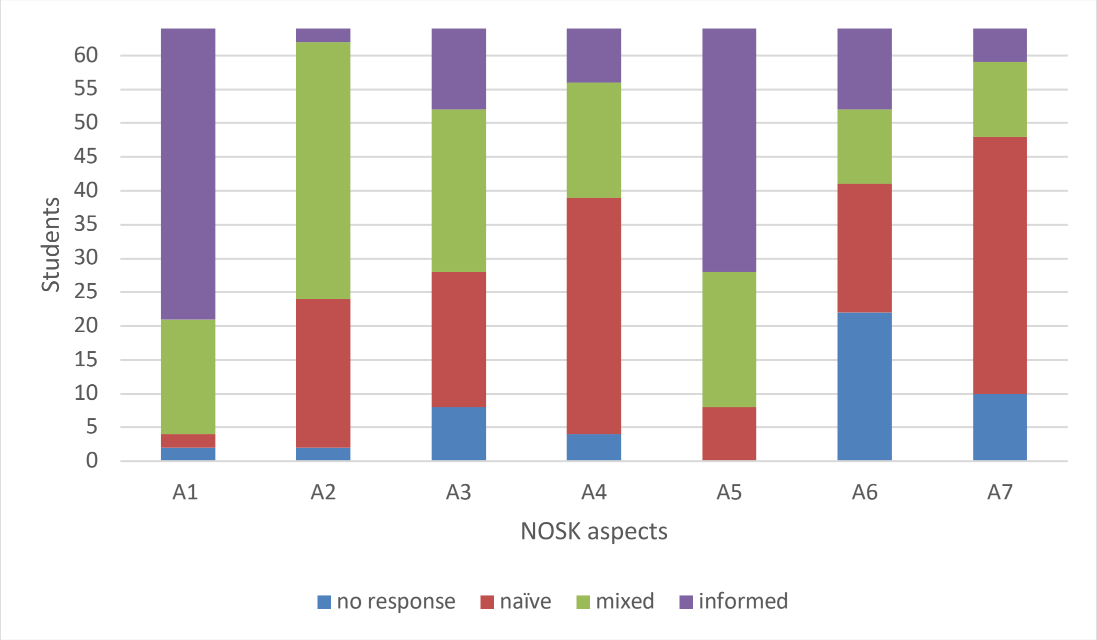
Additionally, semi-structured interviews were conducted with five students who responded to an open call at the end of the whole process. The interviews provided further insights into students' understanding of NOSK and their confidence in designing lesson plans that incorporate NOSK aspects.

Results and Discussion

Students' NOSK Views Before And After The Program

Analysis of students' VNOS-D+ responses before the program indicated distinct patterns in their views on the NOSK aspects. Students' responses were categorized into four levels (no response, naïve view, mixed view, and informed view). The distribution of students' views across the NOSK aspects is presented in Figure 1.

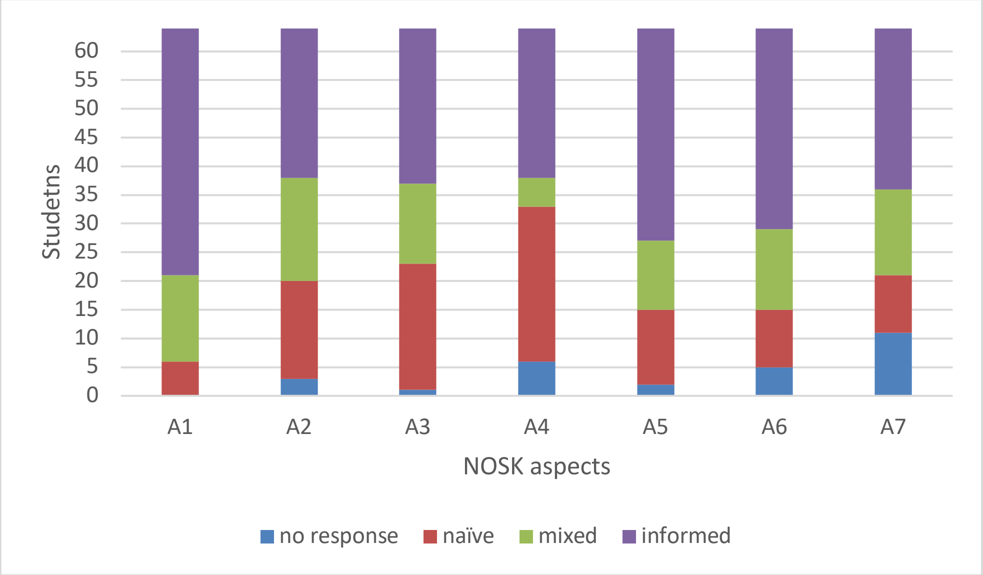
Figure 1. Results from the VNOS-D+ questionnaire before the beginning of the program.



As shown in Figure 1, students demonstrated relatively high levels of awareness of the empirical (A1) and tentative (A5) aspects of NOSK, whereas limited awareness was observed for the subjective aspect (A4) and for the distinction between scientific theories and laws (A7). Mixed views were prevalent regarding the differences between observations and inferences (A2) and the creative aspect of science (A3). Concerning the A2 aspect, most students mentioned that "models illustrate scientific evidence", but their explanations often revealed limited understanding of how models support the interpretation of evidence, as reflected in statements such as "scientists insert data into a specific model and interpret the evidence taken out". Regarding creativity, all students acknowledged its role in the design of new experiments, but half of them did not refer to its presence during data collection and analysis. Twenty students claimed that creativity, in the form of ingenuity, is involved in all stages of scientific research, with twelve of them providing elaborated explanations, like "*Creativity appears at every stage of scientific research, especially when a scientist gets stuck and has to think of new ways to use the available data. Through the* *scientist's inventiveness and insight, scientific knowledge expands*». Many students (22/64) did not respond to items related to the culturally embedded aspect of science (A6). Among those who did respond, naïve views were dominant: ten students focused primarily on ethical dilemmas faced by scientists, while ten others emphasized scientists' interactions with the social and cultural context in which they live.

Following the completion of the program, students' understanding of NOSK aspects, inferred from the analysis of their lesson plans and compared with their initial views, is presented in Figure 2.

Figure 2. Post-test NOSK aspects understanding, inferred from the lesson plans.



As shown in Figure 2, students' understanding improved across all NOSK aspects after the completion of the program. High levels of informed views (A1 and A5) were maintained, with fewer naïve answers. Evidence of improved understanding was also observed for the difference between observations and inferences (A2), which was articulated in approximately half of the lesson plans through the consistent use of appropriate verbs. Similarly, twenty-eight students were able to correctly describe the distinction between scientific theories and laws (A7). The creativity (A3) and objectivity (A4) aspects were clearly developed. Regarding the creativity aspect, students who described it correctly connected it with the role of critical experiments and the use of alternative models in data interpretation. Objectivity was frequently discussed as a collective and temporal achievement: students described how an initially tentative explanation becomes established as scientific knowledge through repeated observations and the contributions of multiple scientists over time. Finally, regarding the culturally embedded aspect (A6), thirty-five students linked scientific knowledge to the social and historical conditions of different eras, referring, for example, to the impact of the Catholic Church on Galileo's work, which did not apply during Newton's era.

Teaching Approaches Used In Students' Lesson Plans

Students employed different teaching approaches to integrate NOSK aspects in their lesson plans. Specifically, NOSK was addressed through approaches drawing on the History of Science (HOS), Scientific Inquiry (SI), Socio-scientific Issues (SSI), or combinations of these approaches. The distribution of teaching approaches across the 64 lesson plans is presented in Table 2.

As shown in Table 2, most students used a combination of Scientific Inquiry and History of Science. In these lesson plans, students combined historical narratives describing the development of scientific concepts (usually through YouTube videos) with inquiry-based activities, such as simulations or laboratory experiments related to the phenomenon under study. Lesson plans based exclusively on the History of Science approach relied exclusively on historical narratives, whereas those adopting a Scientific Inquiry approach focused mainly on experimental or simulation-based activities.

Table 2. Teaching approaches used in the lesson plans.

Teaching approach	Number of lesson plans
History of Science	6
Scientific Inquiry	22
Socio-scientific Issues	3
History of Science/Scientific Inquiry	28
All three combined	1
Completely traditional lesson plan	4

Lesson plans adopting a Socio-scientific Issues (SSI) approach were relatively limited in number. Specifically, three lesson plans addressed NOSK aspects through SSI: one focused on electric circuits and two on climate-related topics taught in Geography. In addition, one lesson plan combined all three teaching approaches (History of Science, Scientific Inquiry, and Socio-scientific Issues) and was developed in the context of a biology lesson on respiration taught in the 10th grade.

Table 3. Duration of teaching periods in the lesson plans.

Teaching periods	Number of lesson plans	Teaching periods	Number of lesson plans
1	8	6	1
2	38	7	0
3	9	8	1
4	6	9	0
5	0	10	1

The average duration of students' lesson plans was 2.48 teaching periods, as shown in Table 3. Thirty-eight students (more than half) developed lesson plans with a duration of two teaching periods, which constituted the most common choice. Lesson plans lasting three teaching periods were proposed by nine students, while a single teaching period lesson plan was designed by eight students. Two students suggested a whole project through their lesson plans, with durations of eight and ten teaching periods. Overall, the distribution of lesson plan duration indicates that all students, apart from eight, recognized the need for extended instructional time to support discussion and the organization of learning activities when integrating NOSK aspects. At the same time, the presence of lesson plans designed for a single teaching period highlights the practical difficulty of addressing both scientific content and NOSK within limited instructional time.

The topics addressed in the students' lesson plans are presented in Table 4. The distribution shows that certain topics were selected more frequently, such as free fall and horizontal throw, whereas other topics appeared only once across the lesson plans, including the photoelectric effect, respiration, and heat transfer.

Adequacy Of Students' Lesson Plans With Respect To NOSK

At the end of the lesson plan, students completed a table indicating which NOSK aspects they had addressed and how these aspects were integrated into their instructional design. Analysis of the lesson plans showed varying levels of adequacy in the integration of NOSK aspects. Based on predefined criteria, lesson plans were classified into three categories: (a) sufficient lesson plans, which integrated multiple NOSK aspects in informed ways through explicit and reflective instructional approaches; (b) partially sufficient lesson plans, in which NOSK aspects were present but addressed implicitly or inconsistently; and (c) insufficient lesson plans, in which NOSK aspects were largely absent.

Table 4. Topics from lesson plans.

Topics	Times used in lesson plans
Free fall	8
Horizontal Throw	6
Newton's Laws Electric Circuits Electric forces Work/Mechanical Energy	5
Buoyancy Light Atomic models	3
Earthquakes and volcanoes Oscillations Solutions – stoichiometry The climate of Greece Circular motion	2
Photoelectric effect Centripetal force Respiration Momentum Waves Heat transfer	1

Seventeen lesson plans (27%) were classified as sufficient. These lesson plans demonstrated informed views of NOSK aspects and incorporated them explicitly throughout the instructional activities. In these lesson plans, NOSK was discussed in detail through the proposed activities. These lesson plans reflected an understanding that addressing NOSK aspects requires extended discussion, with explicit emphasis on each aspect and opportunities for students to articulate and reflect on their ideas. Ten of these lesson plans explicitly stated NOSK objectives at the beginning of the instructional design. Regarding instructional approaches, eight of the seventeen sufficient lesson plans combined History of Science and Scientific Inquiry, seven used only the Scientific Inquiry approach, and two used only the History of Science. Lesson plans that incorporated Socio-scientific Issues were limited in number and did not fall within this category. Across these lesson plans, the historical narrative was used to introduce all NOSK aspects.

NOSK aspects in sufficient lesson plans were integrated through examples, both in HOS and SI, especially for the creative (A3) and the culturally embedded (A6) aspects, by asking students to finish a story using their current knowledge, by constructing a mind-map of the evolution of scientific knowledge, by introducing the tentative aspect (A5), or by describing a critical experiment, and reflecting on it to highlight creativity (A3). Creativity was also addressed through tasks in which students were asked to design an experiment. The distinction between observations and inferences (A2) was discussed with the use of proper verbs, such as observe, see, feel, note for the first, and infer, conclude, assume for the second. The distinction between theories and laws was also discussed when present (A7).

Twenty lesson plans (42%) were classified as partially sufficient. In these cases, students integrated NOSK aspects implicitly, and they only referred to NOSK in the summary table. While some of these lesson plans reflected an understanding of NOSK aspects, others revealed difficulties in effectively incorporating them into teaching. The NOSK aspects most frequently found to be challenging in these lesson plans were the distinction between observation and inferences (A2), the objective aspect (A4), and the difference between theories and laws (A7)

Finally, twenty lesson plans (31%) were classified as insufficient with respect to NOSK integration. These lesson plans followed traditional science teaching approaches, with NOSK aspects absent even at an implicit level. Four lesson plans contained only lecturing on scientific knowledge.

Insights From Student Interviews

Semi-structured interviews were conducted with five students to further explore their views on NOSK and their experiences with designing NOSK-oriented lesson plans. Interview data provided additional qualitative insights that complemented the findings from the written lesson plans. All students reported that they had not heard of NOSK before the program, neither as a concept nor the aspects, in an organized manner. However, they had heard some aspects, mainly the empirical (A1) and the tentative (A5), and they had assumed the others. One referred to a prior discussion of the relationship between science and society (A6) during secondary education, which had taken place in the context of a language course rather than a science class. Overall, students described recognizing elements of NOSK retrospectively in their school and university experiences and reported that the explicit presentation of NOSK aspects during the program facilitated their understanding.

Interviewed students emphasized the significance of NOSK for enhancing students' understanding of science and fostering scientific literacy. At the same time, three students expressed uncertainty regarding the extent to which in-service science teachers are familiar with NOSK aspects and how to teach them. These students highlighted the need for further professional development opportunities related to NOSK teaching.

Regarding the design of the lesson plan, all interviewees described the task as initially challenging. However, once they had selected a topic and started working on it, they reported gaining clarity on how to proceed. Students noted that the instructional resources provided during the program supported their work, and three students additionally reported seeking out and studying further NOSK-related literature independently.

Discussion

The present study focuses on students' understanding of the Nature of Scientific Knowledge (NOSK), the teaching approaches they adopted when designing lesson plans, and the adequacy of NOSK integration in these plans, after participating in a short training intervention (5-hour program) on NOSK. The findings indicate that, despite a mainly traditional and content-focused curriculum, physics students were able to identify multiple opportunities for integrating NOSK across a range of topics. The development of seventeen (27% in total) sufficient lesson plans further suggests that even short instructional interventions can support students in adopting more explicit and reflective approaches to NOSK teaching.

Regarding the first research question, which concerned students' understanding of NOSK aspects before and after the program, the findings indicate substantial improvement across all NOSK aspects. Students initially demonstrated limited or mixed views on several aspects, particularly those related to subjectivity, the distinction between theories and laws, and the culturally embedded aspect, while they are familiar with the empirical and the tentative aspects. The school curriculum helps students use these two aspects in examples of scientific observations and in narratives of how scientific knowledge evolves. These findings are in line with previous research (Koumara & Plakitsi, 2020). The analysis after the completion of the program revealed more informed and coherent understandings, as reflected in the lesson plans.

With respect to the second research question, which examined the teaching approaches students employed to address NOSK, results show a strong preference for combining History of Science and Scientific Inquiry. This pattern suggests that students perceive these approaches as complementary resources for supporting explicit discussions of NOSK, while approaches based exclusively on Socio-scientific Issues were less frequently adopted.

Finally, regarding the third research question, which focused on the adequacy and explicitness of NOSK integration in students' lesson plans, the findings reveal a mixed picture. Although a notable proportion of lesson plans demonstrated informed, explicit, and reflective integration of NOSK, a considerable number remained implicit or insufficient, pointing to ongoing challenges in translating NOSK understanding into coherent instructional practice. This pattern indicates that some students may not have fully engaged with the provided resources, as reflected in their limited understanding of the NOSK aspects.

Limitations Of The Study

The findings cannot be generalized to all physics students in other institutions, as the participants were drawn exclusively from one university department and reflect the specific curriculum followed by students pursuing a teaching certificate. Moreover, obtaining a teaching certificate is not mandatory in Greece, and some future science teachers may acquire pedagogical qualifications through postgraduate studies, which may involve different forms of preparation.

The instructional program was short-term, so a deeper and more sustained understanding is likely to require longer-term engagement, including repeated opportunities to teach NOSK in authentic classroom settings.

Lastly, even though students received feedback on their lesson plans, they were not required to revise or resubmit their work. This means that some students might have enhanced their understanding of NOSK.

Conclusion

This study examined physics students' understanding of the aspects of the Nature of Scientific Knowledge (NOSK) and their ability to integrate these aspects into lesson planning following a short, focused instructional program. The findings indicate that, although students initially held mostly mixed views on several NOSK aspects, targeted instruction can support meaningful development in both NOSK understanding and instructional application. A notable proportion of students were able to design lesson plans that explicitly and reflectively integrated NOSK aspects within the existing secondary science curriculum. This outcome suggests that even short-term interventions can enable pre-service teachers to move beyond content-focused instruction and to consider NOSK as an integral component of science teaching. Further engagement with NOSK is needed before these students can integrate NOSK into their classrooms when they become regular teachers.

Future Work

Future research could build on the present findings by examining the effects of sustained and iterative NOSK-focused instruction embedded within undergraduate science teacher education programs. In parallel, extending NOSK-focused professional development to in-service teachers would provide insight into how teaching experience shapes NOSK integration in contexts where NOSK is not explicitly emphasized in the curriculum. Comparative studies involving pre-service and in-service teachers could further elucidate the role of classroom experience in shaping both NOSK understanding and its instructional enactment. Finally, comparative investigations of instructional approaches, such as History of Science, Scientific Inquiry, and Socio-scientific Issues, could clarify their respective affordances for supporting sustainable NOSK integration across scientific domains and educational levels.

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Primary Teachers' Competencies And Difficulties In Teaching Measurement Uncertainty: Pedagogical Challenges Related To Nature Of Science

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This paper investigates the primary teachers' ability to explicitly address scientific practices and particularly the nature of measurement into their experimental teaching scenarios after their participation in a related STEM Education Master's degree course. The content of the course attended by the primary teachers was based on "Guide to the expression of Uncertainty in Measurement", adapted to primary teachers' level and needs. Primary teachers' teaching scenarios were qualitatively analysed to examine whether and to what extent they have addressed aspects of measurement practices. Preliminary findings show that although primary teachers can design experimental activities for their students, setting explicit learning goals related to measurement procedures, they focus on limited aspects of scientific measurement, such as the causes of measurement uncertainty. They do not frequently mention aspects such as the use of statistical tools, the significance of measurement spread and the need for repetitions of measurements. Preliminary findings provide evidence for further research on how difficulties in teaching measurement concepts are related to difficulties in understanding Nature of Science, and particularly aspects related to observation, evidence, inference, laws and theories.

Keywords: Nature of Science, Measurement

Introduction

Measurement has a long history, stretching back at least two and a half thousand years across a multitude of cultures. Teaching about measurement is closely related to teaching about science, since natural sciences are very connected to measurement procedures. The concept of measurement uncertainty includes key concepts of the scientific method: random and systematic error, calibration, hypothesis testing, experimental design, modelling, approximation, etc. It can be considered as one of "threshold concepts" in science teaching, as it is important for students to identify different sources of uncertainty, quantify results, and take these results into account when planning experiments, analysing data and drawing logical conclusions.

Understanding scientific measurement has been recognized for a long time as an important part of science education by policy bodies (AAPT, 1998; OECD, 2023). Teaching and learning about scientific measurement are an essential aspect of scientific literacy (Osborne et al., 2003). The IPCC 6th Assessment Report (2023) for citizens is indicative of how scientists communicate results to non-scientists. Citizens must be fluent in the concept of measurement and uncertainty in order to be able to read, understand and interpret results in order to inform decisions. This way, uncertainty increases, and does not decrease, confidence in science.

Nature of measurement is also related to scientific and engineering practices, in the context of Next Generation Science Standards (NGSS Lead States, 2013). Particularly, NGSS addresses both measuring processes: (1) collect data (determining the size, materials, precision, etc), and (2) process the data, as depicted in the scientific practices. According to NGSS, during planning and carrying out investigations, students should be able to produce data to serve as the basis for evidence: decide on types, quantity, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data. Moreover, regarding using mathematics and computational thinking, students are expected to measure, estimate, and/or graph quantities such as area, volume, weight, and time to address scientific and engineering questions and problems. Greek primary science education curricula also include learning goals relative to measurement procedures. Students are introduced to the measurement of various quantities, from measuring length, mass, area, volume, duration, and temperature to calibrating thermometers under teacher guidance. At this point, it can be noted that both international and national programs are ambitious about measurement skills in primary education.

Despite the importance of teaching and learning measurement procedures, few studies have dealt with young children's reasoning about measurement and teachers' competencies in responding to difficulties. Regarding primary students' difficulties in measurement, they are focused on the concept of uncertainty. The realization of data incorporates an inherent uncertainty leading to imperfect measurements, confuses students who take science's clarity and certainty for granted. During experimental procedures students expect "a unique right answer" to any measurement. For them, a scientifically correct measurement is the one that is not accompanied by any uncertainty (Allie et al., 2003). Students do not separate the terms error and uncertainty. They use the terms interchangeably, as they attribute to "human error" any of the unexpected results (Allie et al., 2003). The work of Buffler et al (2009) has revealed a strong relationship between measurement uncertainty understanding and students' views on Nature of Science (NoS).

Regarding undergraduate science students, although they are very skilful in carrying out experiments and data analysis, they seem to have difficulties in realizing the reasons for such processes (Buffler et al., 2001). Particularly, science students have difficulty in distinguishing accuracy and precision, and they consider the first data as "prominent" and the following as "confirmatory" (Majiet & Allie, 2019). Regarding primary teachers, very limited research is available, revealing teachers' inability to articulate their knowledge of concepts and processes related to measurement (O'Keefe & Bobis, 2008). Georgaki & Stefanidou (2023) found that although most teacher students recognize scientific measuring as an important part of the scientific process, they had several difficulties regarding the concept of uncertainty, such as not distinguishing between uncertainty in the kitchen and uncertainty in the laboratory, attributing uncertainty in systematic errors and inability to conceptualize random errors as part of the measurement precision. The above-mentioned research findings gave rise to this research, which investigates if and to what extent primary teachers can address measurement concepts in their experimental teaching scenarios, and particularly what the arising difficulties are.

Methodology

Research Questions

According to the work of Munier et al (2013), the research questions are as follows: What difficulties do primary teachers face when designing experimental teaching scenarios including learning goals and teaching activities regarding:

1. Causes of uncertainty (quantity, instrument, and the experimenter)?
2. Statistical tools such as frequency tables and bar charts to represent data and results?
3. Need for multiple measurements

Sample – Place – Time

The research took place during the academic year 2024-2025, in the Department of Pedagogy and Primary Education, of the National and Kapodistrian University of Athens. The sample was a convenience sample and consisted of 30 primary teachers, who attended a Master's Degree program on STEM Education, and particularly a course on Measurements and Sensors.

The Educational Framework

All participants attended the course Measurements and Sensors, which included 10 three-hour laboratory meetings in person. The course had two main parts: The first half (five laboratory meetings) aimed at introducing graduate students in measurements and uncertainty. The content was based on the work of Buffler et al (2008), tailored for primary teachers, in the context of GUM approach. Primary teachers (graduate students) familiarized themselves with the concepts of measurand and units of measurement, producing data of length, mass, volume, time, temperature, voltage and current. Participants were introduced to the concept of uncertainty of measurement and the difference between uncertainty in "everyday" measurements and "scientific" measurements. During the process, they familiarized themselves with basic elements of measurement theory, such as the classification of errors as systematic and random, they participated in certain activities on precision and accuracy and worked on the need for repetitions of measurements. Finally, students, through simple examples, were introduced to the concept of error propagation.

Data Collection And Analysis

Participants in the present study were asked to produce a two-hour experimental teaching scenario on a topic of their choice for primary school, and especially grades K-5 and K-6. The main sources of data were participants' teaching scenarios and field notes.

Data were analysed according to the qualitative content analysis method (Mayring, 2015). For reliability reasons, all data were independently analysed by the two authors, to debate possible differences and reach a final classification. Both teaching goals and teaching activities were analysed regarding: 1. The identification of causes of uncertainties 2. The use of statistical tools and 3. The need for repeatability.

Findings

The first findings reveal that primary teachers, graduate students of a Master's degree program in STEM education, are able to design experimental teaching scenarios focusing on the concept of measurement uncertainty. Analysis of their teaching scenarios reveals that although they all have learning goals related to measurement procedures, not all aspects are equally represented.

Particularly, regarding the first research question (causes of uncertainty related to quantity, measuring instrument and the experimenter), the analysis showed that the majority of the teaching scenarios (20 out of 30) included both learning goals and corresponding activities addressing this issue. Teachers tended to introduce the distinction between systematic and random errors explicitly, indicating an awareness of different sources of measurement uncertainty. However, in many cases, the identification of errors was implicit rather than formally defined, often embedded within given examples or classroom discussions. Additionally, teachers frequently encouraged students to record and reflect on variables that could influence measurements, such as light conditions or distance, typically through guiding questions like "Why do measurements differ?". This suggests that while teachers recognized and addressed factors contributing to uncertainty, these were often approached in a contextual and exploratory manner rather than through formalized conceptual frameworks.

With respect to the second research question (use of statistical tools), only a limited number of teaching scenarios (10 out of 30) included explicit learning goals and activities related to data representation and analysis. When statistical tools were addressed, teachers mainly focused on designing and/or explaining simple graphical representations, such as temperature–time graphs, or on interpreting ready-made diagrams and bar charts by asking students to provide explanations of the displayed results. In addition, some scenarios included basic calculations of averages. However, teachers' engagement with statistical thinking remained limited, as more advanced concepts, such as the importance of the spread or variability of measurements, were entirely absent from the teaching scenarios. Overall, statistical tools were approached in a procedural manner, emphasizing representation and calculation rather than deeper reasoning about data.

Concerning the third research question (the need for multiple measurements), fewer than half of the teaching scenarios (12 out of 30) explicitly emphasized the importance of repetition. In these scenarios, teachers typically supported repeated measurements by providing pre-structured data tables for students to complete and by encouraging comparisons between different groups' data sets. Some activities also prompted students to reflect on the reasons for conducting multiple measurements. Nevertheless, repetition was mainly treated in a mechanical way, focusing on the act of repeating measurements rather than on its epistemic role. Links between repeated measurements and key concepts such as reliability or precision of results were largely absent, and only limited emphasis was placed on the significance of measurement spread. This indicates that, although repetition was operationally included, its conceptual importance in experimental inquiry was not sufficiently developed.

Implications For Nature Of Science Teaching

The difficulties identified in teaching measurement concepts have important implications for the teaching of the Nature of Science (NoS). Measurement uncertainty can foster essential habits of mind for scientific reasoning and citizenship in a world shaped by science and technology. Shifting the focus from "error" to uncertainty can help students move away from a rigid right–wrong view of science and toward an understanding of scientific knowledge as tentative, evidence-based, and open to revision. By grappling with uncertainty, students are more likely to appreciate experimentation as a process of inquiry rather than a procedural search for correct answers, and to interpret data not as absolute truths but as results associated with a range of confidence. This perspective mirrors authentic scientific practice, where scientists rarely obtain a single "true" value but instead report results in terms of precision, accuracy, and confidence intervals. Moreover, challenges in teaching measurement uncertainty are closely linked to broader NoS dimensions, including observation, evidence, inference, the relationship between laws and theories, and the objectivity and subjectivity of measurement processes, as well as the intersubjective nature of scientific results (Stefanidou & Skordoulis, 2014; Mari et al., 2017; Stump et al., 2024). Explicit attention to distinctions such as accuracy versus precision can therefore support a more coherent integration of measurement concepts and NoS, enhancing students' understanding of how scientific knowledge is constructed.

Conclusions

Overall, the findings indicate that primary teachers face substantial difficulties when designing experimental teaching scenarios that meaningfully address measurement uncertainty. Although some aspects of uncertainty are acknowledged, teachers' approaches largely remain at the level of broad or implicit discussion, without a clear conceptual distinction between error and inherent uncertainty. The limited use of statistical tools further suggests a lack of familiarity with integrating basic statistical reasoning into experimental teaching, restricting students' opportunities to interpret data beyond simple representations or averages. Similarly, while the need for repeated measurements is occasionally emphasized, it is often treated mechanically without adequately highlighting its role in reducing uncertainty or improving the reliability and precision of results. Taken together, these findings reveal that key dimensions of experimental reasoning—such as variability, confidence in measurements, and the epistemic status of data—are insufficiently addressed, pointing to a fragmented understanding of measurement uncertainty in primary science teaching.

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The Growing Need For STEM Careers And The Potential Pathways For Independent Scientists

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The growing demand for STEM professionals highlights the need to explore alternative career pathways for scientists beyond traditional academia and industry. Despite efforts to encourage STEM career persistence, issues such as limited academic positions hinder long-term engagement in scientific fields. The mismatch between PhD holders and private sector employees further exacerbates this challenge, necessitating new opportunities for independent researchers.

This study investigates the potential of non-profit organizations as viable career alternatives for STEM professionals in Japan by analysing research funding trends. Using data from the KAKEN database, we examine the research achievements of non-profit research institutions, such as general incorporated associations (GIA), non-profit organizations (NPO), and social welfare corporations (SWC). Our findings revealed that independent researchers within these organisations' secure competitive grants, with notable participation in early career and small-scale research funding schemes.

Case studies highlight two key patterns: organisations that collaborate with universities to support early career researchers, and those that sustain long-term, independent scientific enquiry. While some organisations provide transitional opportunities for post-doctoral researchers, others enable senior scientists to continue their work beyond academia. Despite financial and institutional barriers, these alternative research pathways contribute to scientific progress and expand STEM career possibilities.

This study underscores the importance of recognising and supporting independent research outside conventional institutions. Future research should involve qualitative interviews to explore the professional development of independent scientists. By addressing funding challenges, we can foster a more inclusive and sustainable STEM workforce that ensures diverse contributions to scientific innovation.

Keywords: Independent Researcher, Academic Career, Scientist

Introduction

STEM Career And Becoming Scientists

The increasing global demand for STEM (Science, Technology, Engineering and Mathematics) professionals contrasts with a decline in student interest in STEM careers, a phenomenon known as the 'leaky pipeline.' Factors such as school experiences, parental influence, economic background, and gender shape students' motivation (DeWitt & Archer, 2015; Zhai & Liu, 2024). Despite their academic abilities, many students lose interest as they advance their education (Chen et al., 2024).

At the doctoral level, the oversupply of STEM graduates leads to employment challenges. A report by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT, 2023) shows that only 15.8% of PhD holders secure university faculty positions, with 9.4% working as post-doctoral researchers. Many PhD graduates struggle to transition into industry because of a mismatch between their skills and corporate needs (Miki, 2019). While academia remains a primary aspiration, the reality of limited faculty positions has driven interest in alternative career pathways, including independent research.

Rise Of Scientists Outside University

There is growing attention and support for citizen scientists. 'Citizen science' indicates research activities conducted by non-professionals in science. (Silvertown 2009, Lusse et al. 2022). This can be performed independently by citizens or collaboration with professional scientists. In Japan, there is a framework for amateur scientists (Kimura 2021). An amateur scientist is a non-professional researcher with expertise in a specific scientific field, such as entomology, at a level comparable to or exceeding that of professional scientists in the same discipline. Here, 'non-professional' denotes individuals who do not rely on this activity as their primary source of income. The National Coalition of Independent Scholars defines independent scholars as individuals engaged in research without a tenure-track position or permanent university contract established in 1989. There are communities of independent researchers, such as the Japan Scientists' Association (JSA), established in 1965. These organisations have their own peer-reviewed journals and face challenges in sustaining their activities due to limited research funds. I It is not appropriate to categorise independent scientists into citizen science or amateur science as are capable of drafting their own academic papers.

Therefore, this study focuses specifically on the funding challenges for independent scientists in Japan. Funding is one of the key factors impacting the the sustainable development of these so-called non-professionals. Exploring their funding achievement, makes it possible to discuss pursuing STEM careers as 'scientists' outside academia or industry. The research question in this study is as follows: Can non-profit organisations be an alternative career path for STEM professionals from the perspective of acquiring funding?

Japanese Research Grants

This study examines the Grants-in-Aid for Scientific Research (Kakenhi) funded by the Japanese government through the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) and the Japan Society for the Promotion of Science (JSPS). Only researchers affiliated with recognised institutions are eligible to apply for these grants. These research organisations should fulfil the listed criteria, such as 'At least 1/5 of the researchers who are currently affiliated with the applicant institution at the time of application have published an original paper in a journal or similar publication within the past year', and 'The per capita research expenditure of the applicant organisation as a whole, excluding external funds (the amount for the previous year of the application), must be at least 360,000 yen per year' (MEXT 2021). This requirement ensures that researchers have completed seminars on research ethics and integrity and grants are used properly.

According to the list of research organisations of KAKEN (JSPS 2022), there are five main categories of research organisations in Japan: 1) universities, 2) colleges and technical colleges, 3) inter-university research institutions and foundations, 4) independent administrative institutions, and 5) others. In this paper, we discuss those organisations in the last group. By doing so. we can determine what kind of research is being conducted in such organisations and what challenges exist. This would ensure the diversity of places where researchers can become active in society.

Methods

Sample And Data Collection

The KAKEN database (NII 2023) was used for analysis, covering 1,043,559 research projects from 1964 to 2024. The list of research organisations (JSPS 2022) was collected in January 2024. Based on this list, organisations were categorised using a numbering system. In total, 2059 organisations are listed in the list. Serial numbers were assigned to each organisation.

Organisation numbers starting with 1, 2, and 3 were universities (N=825); those starting with 4, 5, and 6 were colleges (N=313), technical colleges (N=58), and inter-university institutions (N=16), respectively; and those starting with 7, 8, and 9 were others (N=845). 'Others' included foundation organisations, national corporations, stock companies, medical corporations, specified non-profit-making corporations, welfare corporations, and religious groups. To examine only the organisations needed to work as professional researchers outside of universities or companies, this study has focused on organisations that do not run for profit; therefore, general incorporated associations (GIA), non-profit organisations (NPO), and social welfare corporations (SWC) were studied.

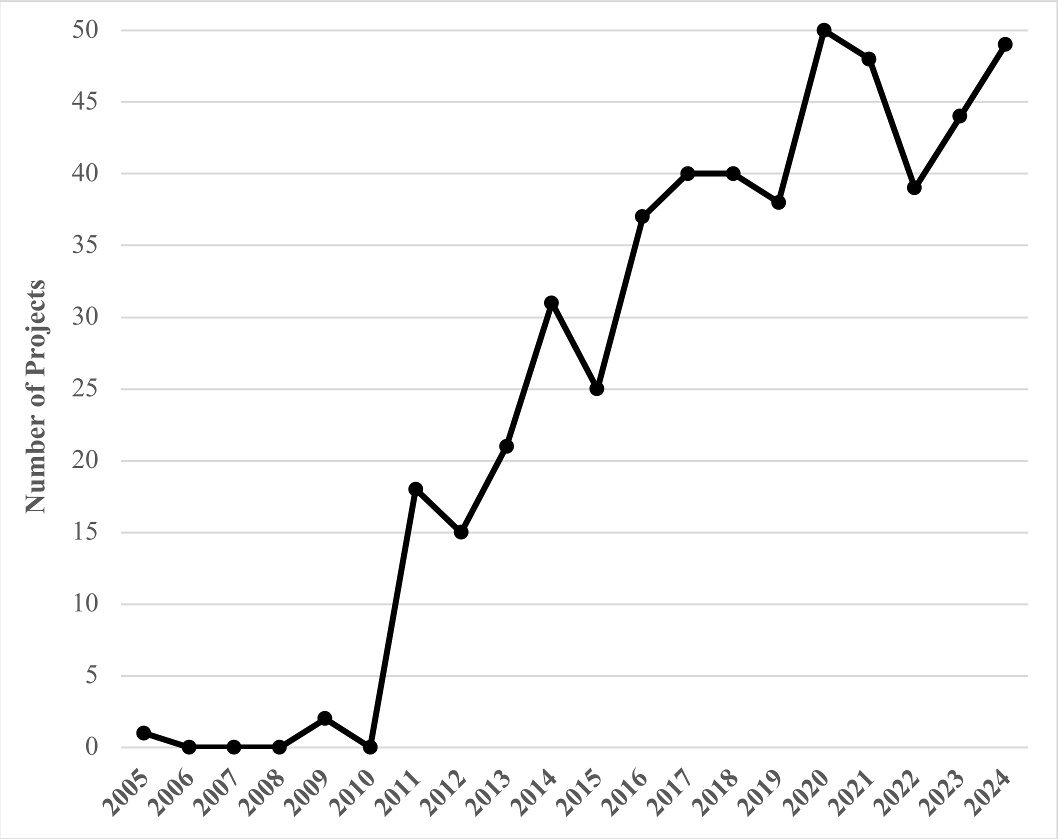
Based on the KAKEN database, we looked into the following categories for GIA, NPO and SWC; 1) Number of research projects; and 2) Budget types and actual budget.

Results

Trends In Research Funding

Figure 1 indicates that there has been a clear, rapid growth in the number of research projects accepted by Kakenhi. This growth can be explained by the National University Corporation Act, enacted in 2004. Before 2004, Japanese national universities were government agencies; afterwards, they became National University Corporations. Universities still receive funding from the government; however, the funds are decreasing annually, primarily due to the overflow of post-doctoral students. Researchers have attempted to find opportunities to conduct research outside universities.

Figure 1. Number of Research Projects.



Budget Types

There are several budget types varies its duration and total budget. Table 1 summarises current budget types. For example, Grants-in-Aid for Scientific Research (A, B, C) fund research projects by one or more researchers for three to five years, with a total budget of less than 5,000,000 JPY, between 5,000,000 JPY and 20,000,000 JPY, between 20,000,000 and 50,000,000 JPY. Grants-in-Aid for Early-Career Scientists funds research projects run by young researchers under the age of 39 or who have been awarded a doctoral degree for less than 8 years excluding the parental leave period for two to four years. Researchers who have been awarded a doctoral degree within the past eight years are eligible for amounts up to 5,000,000 JPY for a duration of 2–5 years.

Table 1. Budget Type and Numbers.

Name	Budget
Grant-in-Aid for Transformative Research Areas	less than 5,000,000 JPY or between 5,000,000 and 30,000,000 JPY
Grant-in-Aid for Scientific Research (S)	between 50,000,000 and 200,000,000 JPY
Grant-in-Aid for Scientific Research (A)	between 20,000,000 and 50,000,000 JPY
Grant-in-Aid for Scientific Research (B)	between 5,000,000 JPY and 20,000,000 JPY
Grant-in-Aid for Scientific Research (C)	less than 5,000,000 JPY
Grant-in-Aid for Research Activity Start-up	less than 3,000,000 JPY
Grant-in-Aid for Early-Career Scientists	less than 5,000,000 JPY
Grant-in-Aid for Challenging Research (Pioneering)	between 5,000,000 JPY and 20,000,000 JPY
Grant-in-Aid for Challenging Research (Exploratory)	less than 5,000,000 JPY

On average, an organisation obtains ¥8,055,361 per research project. There was a preference for relatively small projects. The minimum budget recorded was ¥520,000; the maximum budget was ¥131,040,000. Figure 2 (next page) shows the overview of budget types. Among these budget types, Early-Career Scientists (153) and Research Activity Start-ups (13) represented grants awarded to young scholars, comprising 34% of the total number of grants. This indicates that these researchers were not necessarily in the early stages of their careers. Their research projects are evaluated worthy of funding.

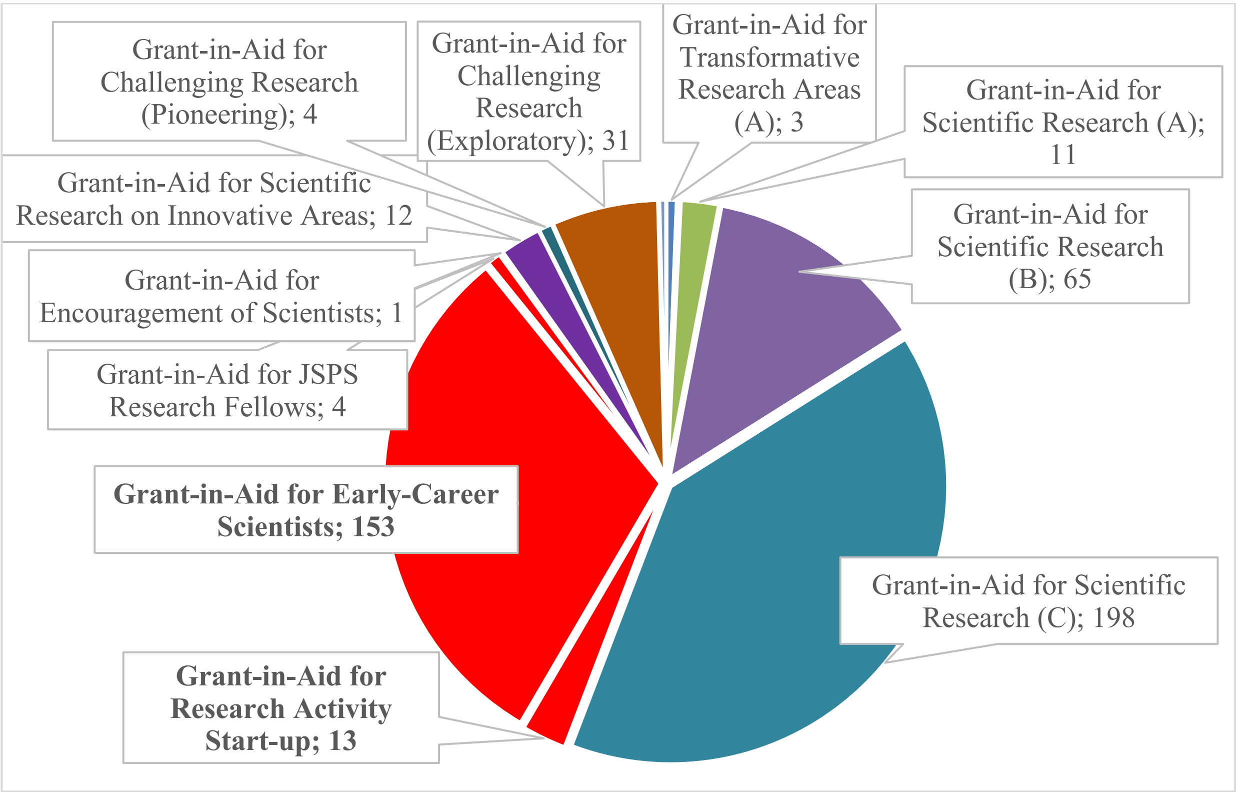
Preliminary Case Study

Two major organisations were analysed in depth by collecting information on webpages of organisations. There are two main patterns in how organisations conduct research projects. Some collaborate closely with universities, where principal investigators are typically university professors, and researchers stay for a short period before securing academic positions. In contrast, some organisations, particularly in natural sciences with theoretical research areas, operate independently for over five years with small teams (under ten researchers). These groups secure substantial funding and are often led by senior researchers, including retired university faculty members who continue their work outside academia.

Conclusion and Further Research

This study highlights the increasing number of independent researchers in Japan and their contributions to scientific progress. It states that researchers can work as independent professional scientists in non-profit organisations; these independent scientists are actively conducting Kakenhi-funded research. Studies on research outside universities remain limited; various researchers, including those working independently, pro bono, or as a second job, have contributed to expanding the research landscape. Thus, students' career pathways can expand, which would contribute to STEM career opportunities. Although funding opportunities exist, institutional barriers continue to pose significant challenges. Independent research can serve as a viable career path, ensuring greater flexibility and resilience in STEM professions. This research aims to demonstrate how such career paths can offer greater flexibility and resilience in STEM professions and furthermore, raises the question: “Who are scientists, and what are the professionality of scientists?”.

Figure 2. Overview of Budget Types.



Acknowledgement

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Pre-Service Teachers' Engagement Of Scientific Reasoning: Uncovering The Mystery Of Tutankhamun's Iron Dagger

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This instrumental case study examines how pre-service teachers engage in scientific reasoning when confronted with an anomalous historical case: Tutankhamun's iron dagger. Sixty-two pre-service teachers from diverse disciplines participated in an inquiry task during the first week of a Science and Research Ethics course. Written responses were analysed using a hypothetico–deductive reasoning framework supported by a rubric-based analysis. Findings indicate that most participants demonstrated minimal or basic inquiry engagement, generating a wide range of explanations from scientifically plausible to pseudoscientific. Findings highlight the need for stronger scientific reasoning skills in teacher education to foster critical thinking and scientific literacy.

Keywords: Scientific Inquiry, Scientific Reasoning, Pre-Service Teachers

Introduction

In contemporary, media-saturated societies, individuals are increasingly required to evaluate scientific and pseudoscientific claims in everyday life. Consequently, scientific literacy extends beyond content knowledge to include the ability to reason scientifically, construct explanations, and justify claims with evidence (McNeill, 2008; Lawson, 2009). From this perspective, learning science involves engaging in the practices of science—such as generating hypotheses, evaluating evidence, and reasoning under uncertainty—rather than merely acquiring established facts. Inquiry-based science learning has been shown to support the development of scientific reasoning, increase student motivation, and promote critical thinking and problem-solving skills (Murphy et al., 2019; Taibu et al., 2021). However, research consistently indicates that both teachers and pre-service teachers often have limited opportunities to engage in authentic scientific inquiry and therefore struggle to support these practices in their future classrooms (Uyar et al., 2018). In addition, research on scientific reasoning consistently emphasizes the central role of causal and mechanistic reasoning in constructing scientific explanations. Scientific understanding requires not only identifying causes and effects but also articulating the mechanisms through which causes produce observable outcomes (Ahn & Kalish, 2000). Russ et al. (2008) argue that reasoning about mechanisms is a fundamental aspect of scientific inquiry, as mechanisms link evidence to explanation by specifying the processes underlying phenomena. Similarly, Abrams and Southerland (2001) suggest that learners often prioritize explaining why a phenomenon occurs rather than how it occurs, thereby neglecting the physical or causal mechanisms required for scientifically valid explanations.

One promising approach for eliciting and examining scientific reasoning is the use of anomalous cases—situations that conflict with established scientific or historical expectations. Anomalies create epistemic tension, prompting learners to generate hypotheses, reconsider assumptions, and evaluate evidence (Chinn & Brewer, 1993; Echevarria, 2003). Historically grounded anomalies are especially powerful because they situate scientific reasoning at the intersection of science, history, culture, and ethics, thereby supporting understanding of the nature of science (NOS) as a dynamic and human endeavour (Allchin, 2013). The discovery of an iron dagger in the tomb of the Egyptian pharaoh Tutankhamun (1332–1323 BCE) represents such an anomaly. According to conventional historical timelines, iron processing became widespread several centuries later, making the presence of an iron artifact in this context unexpected. Explaining this finding requires reasoning under uncertainty, generating alternative hypotheses (e.g., meteoritic iron, early metalworking, trade), and evaluating their plausibility based on historical, chemical, and archaeological considerations. As such, the case provides an authentic context for examining how learners engage in scientific inquiry and hypothetico–deductive reasoning.

Although scientific inquiry has long been a central focus of science education research (Fukuda et al., 2022), relatively few studies examine how pre-service teachers' inquiry capabilities are revealed when they engage with authentic, anomalous scientific problems (Vo & Simmie, 2024). Understanding how pre-service teachers initially reason in such contexts is critical, as these epistemic practices shape how they will later design learning environments for their own students.

In the present study, the iron dagger represents an anomalous result—a finding that conflicts with established historical and scientific expectations—and therefore requires learners to reason with uncertainty, generate competing hypotheses, and judge the plausibility of explanations based on evidence. Research on students' engagement with anomalous results shows that such situations are particularly powerful for revealing how learners monitor evidence, evaluate claims, and regulate their reasoning processes, which are central components of scientific literacy (Crujeiras-Pérez & Jiménez-Aleixandre, 2017; Echevarria, 2003). Besides, historically grounded case studies, particularly those involving anomalies, are uniquely powerful for fostering students' understanding of both scientific inquiry and the nature of science (NOS) (Allchin, 2011). In the Tutankhamun task, pre-service teachers are required to argue for or against explanations (e.g., meteoritic iron, early metallurgy, pseudoscientific claims) using historical, chemical, and archaeological reasoning. Thus, the case operationalizes the broader goal of scientific literacy by making visible how participants reason, justify conclusions, and distinguish scientific explanations from speculative or non-scientific ones—precisely the competencies that science education aims to develop.

Research Question

How do pre-service teachers use scientific reasoning to generate, evaluate, and justify explanations for anomalies in historical scientific findings?

Methods

Research Design

This study was designed as an instrumental qualitative case study (Stake, 1995) examining how pre-service teachers engage in scientific reasoning when confronted with an anomalous historical scientific case. Case study methodology is particularly appropriate when the aim is to investigate complex cognitive and epistemic processes within a bounded context (Yin, 2018). The case of *Tutankhamun's iron dagger* was selected because it represents a historically authentic anomaly that requires hypothesis generation, evidence evaluation, and mechanistic reasoning, making it a powerful context for examining scientific inquiry practices.

Consistent with recommendations for qualitative case studies in education, multiple analytic strategies were employed, including rubric-based scoring and qualitative interpretation, to provide a rich and systematic account of participants' reasoning (Merriam & Tisdell, 2016). The case thus serves as an analytic lens for understanding broader challenges in pre-service teachers' engagement with scientific inquiry and hypothetico–deductive reasoning.

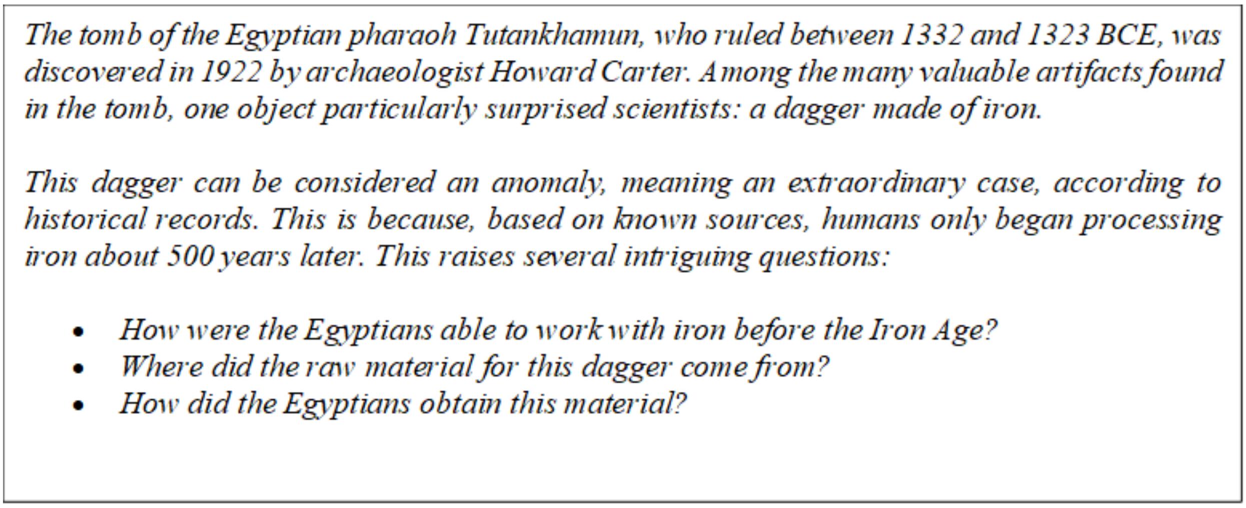
Context And Participants

The study was conducted as part of the Science and Research Ethics course, a compulsory general culture course offered at a faculty of education in Türkiye. The course enrolled 62 pre-service teachers from diverse departments, including preschool education, social studies, music education, science education, and biology education, representing all four undergraduate grade levels (1st–4th year). Purposeful inclusion of participants from different disciplinary backgrounds was intended to capture a broad range of prior scientific knowledge and epistemic orientations, an approach commonly adopted in studies examining inquiry reasoning across heterogeneous teacher populations (e.g. Windschitl et al., 2012).

Data were collected during the first week of the semester, prior to formal instruction, in order to assess participants' readiness and baseline inquiry reasoning. Early-course data collection is recommended when the aim is to examine pre-existing epistemic resources rather than instructional outcomes (Hammer & Elby, 2002).

Instructional Task: A Scientific Mystery: Tutankhamun's Iron Dagger

Participants were presented with a historically grounded anomalous case titled "A Scientific Mystery: Tutankhamun's Iron Dagger." The case described the discovery of an iron dagger in the tomb of Tutankhamun (1332–1323 BCE), an artifact that contradicts established historical timelines for iron metallurgy. The case was deliberately framed as an anomaly, defined as evidence that conflicts with existing theoretical or historical expectations and therefore prompts epistemic tension (Chinn & Brewer, 1993; Echevarria, 2003). The open-ended guiding questions encouraged participants to recognize the anomaly, generate possible explanations, and consider the origin and processing of the material. Participants worked individually and were explicitly guided to formulate hypotheses, without being provided additional evidence or corrective feedback. The study employed the following case scenario:



The tomb of the Egyptian pharaoh Tutankhamun, who ruled between 1332 and 1323 BCE, was discovered in 1922 by archaeologist Howard Carter. Among the many valuable artifacts found in the tomb, one object particularly surprised scientists: a dagger made of iron.

This dagger can be considered an anomaly, meaning an extraordinary case, according to historical records. This is because, based on known sources, humans only began processing iron about 500 years later. This raises several intriguing questions:

- *How were the Egyptians able to work with iron before the Iron Age?*
- *Where did the raw material for this dagger come from?*
- *How did the Egyptians obtain this material?*

Analytical Framework

Participants' written responses were analysed using a Hypothetico–Deductive Reasoning (HDR) framework, which conceptualizes scientific inquiry as the coordinated generation, testing, and evaluation of alternative explanations. According to this perspective, science involves formulating competing hypotheses and deducing consequences that can be tested against evidence, a process that characterizes sophisticated scientific reasoning (Lawson, 2000; Lawson, 2008). This HDR approach has also been elaborated as a cognitive foundation for science learning, with hypothetical thinking constituting a central mode of reasoning employed by both scientists and learners (Kalinowski & Pelakh, 2023). The HDR framework guided the analysis of key inquiry steps, including anomaly recognition, hypothesis generation, use of evidence, and hypothesis evaluation.

- Observation and problem identification
    - Do the pre-service teachers recognize the iron dagger as an anomaly?

  - Do they acknowledge that it challenges established historical knowledge?
- Hypothesis generation
  - Do they propose explanations based on prior knowledge (e.g., meteoric iron, early metallurgy, trade)?
  - Do they suggest multiple possible explanations or fixate on one?
- Use of evidence
  - Do they support their explanations with historical, chemical, or archaeological evidence?
  - Do they reference known facts, studies, or historical records?
- Hypothesis evaluation
  - Do they compare alternative explanations or assess their plausibility based on available evidence?
- Logical consistency in reasoning
  - Do they maintain coherent and logically structured reasoning across observation, hypothesis, and evidence?

Although the analytic framework was grounded primarily in hypothetico–deductive reasoning, elements of the Claim–Evidence–Reasoning (CER) framework (McNeill et al., 2006) were used as a supporting interpretive lens to examine how participants structured their explanations. Within this lens, hypotheses were treated as claims, references to historical or scientific information as evidence, and the logical connections between claims and evidence as reasoning. Consistent with Gotwals et al. (2012), this approach supported the analysis of participants' ability to construct evidence-based explanations within the broader inquiry process.

The framework draws on established models of scientific inquiry that conceptualize inquiry as a coordinated process involving problem recognition, explanatory construction, and evidentiary reasoning (National Research Council [NRC], 2012). The hypothesis revision stage was intentionally excluded, as the purpose of the study was to examine participants' initial explanatory reasoning rather than learning progression.

Rubric Development And Scoring

A four-level analytic rubric (Table 1) was developed to evaluate participants' engagement in scientific inquiry across five criteria. Rubric-based assessment is widely recognized as an effective method for evaluating complex cognitive practices such as scientific reasoning and inquiry, as it allows for systematic yet nuanced analysis of qualitative responses (Jonsson & Svingby, 2007). Each criterion was scored from 0 (absent) to 3 (proficient), yielding a maximum total score of 15. Aggregate scores were interpreted using predefined engagement levels (no, minimal, basic, developing, proficient), categorizing inquiry performance along developmental continua.

The responses of the participating pre-service teachers were evaluated based on each criterion, and the scoring was interpreted as follows:

Scoring Interpretation

- **0 points** →No Engagement in Scientific Inquiry
- **1- 5 points** → Minimal Engagement in Scientific Inquiry (Lacks understanding, weak reasoning, no use of evidence).

- **6 - 10 points** → Basic Scientific Inquiry (Some reasoning present but lacks depth and evaluation of evidence).
- **11 - 14 points** → Developing Scientific Inquiry (Good reasoning, considers evidence but lacks full hypothesis testing).
- **15 points** → Proficient Scientific Inquiry (Strong reasoning, effective hypothesis testing, and evaluation based on evidence).

Table 1. Rubric Criteria and Scoring

Category	Score: 0 (Absent)	Score: 1 (Basic/Naïve)	Score: 2 (Developing)	Score: 3 (Proficient/Advanced)
1. Observation & Problem Identification	Does not recognize the scientific anomaly or problem.	Recognizes the problem but describes it vaguely or inaccurately.	Identifies the problem with some clarity but lacks depth in recognizing its significance.	Clearly identifies the anomaly and articulates why it challenges established scientific knowledge.
2. Hypothesis Generation	No hypothesis is proposed.	Proposes a single hypothesis, but it lacks scientific basis or is a misconception.	Proposes one or more hypotheses with some scientific validity but lacks depth in justification.	Generates multiple plausible hypotheses, supported by logical reasoning and prior knowledge.
3. Use of Evidence (Empirical & Historical)	No evidence is provided to support hypotheses.	Mentions some evidence but does not connect it logically to the hypotheses.	Uses relevant evidence but does not fully explain its significance.	Uses strong, diverse evidence (chemical, historical, archaeological) and logically connects it to hypotheses.
4. Hypothesis Testing & Evaluation	Does not attempt to test or evaluate hypotheses.	Accepts a hypothesis without questioning its validity.	Considers alternative explanations but does not critically evaluate them.	Compares multiple hypotheses and evaluates them based on evidence, revising as needed.
5. Logical Consistency in Reasoning	No clear logical connections between problems, hypothesis, and evidence.	Some logical connections exist but contain gaps or inconsistencies.	Reasoning is mostly logical, but there are minor gaps or weak connections.	Uses well-structured, consistent reasoning that clearly connects the problem, hypotheses, and evidence.

Data Analysis

All participant responses were independently evaluated using the rubric. Scores were first examined descriptively to determine overall engagement patterns, followed by qualitative analysis to identify recurring strengths and weaknesses in scientific reasoning, including reliance on mechanistic explanations versus speculative or pseudoscientific claims. Combining rubric scores with qualitative interpretation is recommended for maintaining analytic rigor while preserving the explanatory richness of participants' reasoning (Miles et al., 2020).

By integrating an anomalous historical case with a structured inquiry rubric, this methodology enables systematic examination of pre-service teachers' initial scientific reasoning, particularly their capacity to generate causal explanations and use evidence.

Findings

Levels Of Scientific Inquiry Engagement

Analysis of pre-service teachers' responses using the Scientific Inquiry rubric revealed that the majority of participants demonstrated limited engagement in scientific inquiry (Table 2). Specifically, 59 of the 62 pre-service teachers (94%) were categorized at the Minimal or Basic inquiry levels, indicating difficulties in coordinating hypotheses, evidence, and reasoning. Only two participants (3%) reached Developing or Proficient levels, while one participant showed no engagement.

Table 2. Pre-service teachers Scientific Inquiry Engagement Levels

Engagement Level	Number of Pre-Service Teachers (N=62)
No Engagement in Scientific Inquiry	1
Minimal Engagement in Scientific Inquiry	29
Basic Engagement in Scientific Inquiry	30
Developing Scientific Inquiry	1
Proficient Scientific Inquiry	1

Participants at the *Minimal Inquiry* level often recognized the historical tension but failed to articulate underlying mechanisms or evaluate evidence. For example, one participant stated, *"History is not a discipline with definitive conclusions… the Egyptians may have discovered iron-processing techniques before everyone else"* (PS2), offering a generalized claim without evidentiary support. Similarly, PS4 acknowledged uncertainty and provided no causal explanation: *"I have no idea where the iron was sourced from."*

In contrast, participants at the *Basic Inquiry* level proposed plausible explanations but demonstrated weak reasoning or incomplete use of evidence. For instance, PS9 suggested early technological advancement—*"Egyptian society may have started processing iron earlier"*—yet did not explain how such processing could have been achieved under known technological constraints of the period. Many responses in this category relied on assertions rather than mechanistic reasoning, such as PS21's statement, *"They may have made the dagger by hammering the iron."*

Only a small number of participants demonstrated *Developing or Proficient Inquiry,* characterized by coherent hypothesis generation, explicit recognition of the anomaly, and coordinated use of historical and chemical evidence. One high-scoring participant clearly articulated the anomaly and supported a mechanistic explanation:

> *"This information calls historical records into question because iron-processing technologies were not widespread in the 14th century BCE. However, the dagger found in Tutankhamun's tomb represents an anomaly indicating that iron was somehow processed during this period. One of the most plausible hypotheses is that the dagger was made from meteoritic iron, as chemical analyses have shown a high nickel content"* (PS1).

Types Of Hypotheses Generated

Across all responses, pre-service teachers generated 15 distinct hypotheses to explain the presence of the iron dagger in Tutankhamun's tomb (Table 3). These hypotheses varied considerably in scientific plausibility, ranging from evidence-based explanations to explicitly pseudoscientific claims.

Scientifically Plausible Hypotheses

As presented in Table 3, eight hypotheses reflected scientifically testable explanations, most commonly invoking meteoritic iron, early metalworking techniques, or trade. Several participants explicitly referenced meteorites as a feasible iron source:

Table 3. Hypothesis Frequency Table

	Hypotheses	Frequency	
1	The dagger was shaped using cold forging (hammering) techniques	9	**Scienrific hypotheses**
2	The dagger was obtained through trade from an advanced civilization that had early iron processing techniques	8	
3	The dagger suggests that iron was used earlier than currently recorded but not widely documented	7	
4	The dagger was processed using high-temperature furnaces or fire-based technique	6	
5	Egyptians unknowingly used iron without recognizing it as a distinct material	5	
6	Iron could have been processed in a different way, such as through exposure to natural environmental heat sources	4	
7	The dagger was created using metal that naturally formed in a way that made it easier to shape	3	
8	The dagger was made from meteoritic iron	2	
9	The dagger was placed in the tomb at a much later date	6	**Non-scientific hypotheses**
10	The dagger was melted and shaped by prolonged exposure to sunlight	5	
11	The dagger was made by a lost ancient civilization with superior technology	4	
12	The dagger was formed by lightning striking iron	3	
13	The dagger was made with the help of extraterrestrials	3	
14	The dagger was created using unknown supernatural or mystical forces	2	
15	The dagger was created using an unknown energy or method lost to history	2	

> *"It was most likely made from meteoric iron… people could shape the iron they found from meteorites by hammering it" (PS60).*

Others emphasized trade and intercultural exchange:

> *"As far as I know, the Egyptians were very advanced in many fields… they may have adopted ideas from other civilizations through trade" (PS33).*

However, even within scientifically oriented hypotheses, many participants struggled to articulate mechanisms, often stopping at surface-level claims without explaining how evidence supported their conclusions.

Pseudoscientific And Speculative Hypotheses

Seven hypotheses were classified as non-scientific, relying on supernatural forces, extraterrestrial intervention, or vague unknown energies. These explanations were typically devoid of evidence or causal reasoning. For example, PS13 stated, *"The dagger may have been made with magic,* "while PS52 suggested, *"I think the pyramids were built by extraterrestrials using more advanced technology."*

Such responses illustrate a tendency to substitute speculation for mechanistic explanation when causal reasoning was inaccessible, a pattern observed across minimal and basic inquiry levels.

Overall, the findings indicate that while many pre-service teachers were able to generate claims, far fewer were able to coordinate claims with evidence and mechanistic reasoning. Explanations frequently addressed why the dagger might exist (e.g., advanced civilization, historical uncertainty) rather than how it could have been produced given material and technological constraints.

Discussion And Conclusion

The findings indicate that most pre-service teachers were minimally or basically engaged in scientific inquiry, despite generating a broad spectrum of reasoning approaches ranging from scientifically plausible hypotheses to pseudoscientific and speculative explanations. This variation highlights the pedagogical value of anomalous cases in teacher education, as anomalies are known to spark curiosity, challenge learners' prior assumptions, and foreground how evidence is interpreted and used in scientific reasoning (Chinn & Brewer, 1993; Allchin, 2013). Tasks based on anomalies can therefore function as diagnostic tools, enabling instructors to identify misconceptions and epistemic weaknesses early and to determine where instructional scaffolding is most needed (Echevarria, 2003; Windschitl et al., 2012). Moreover, historically grounded anomalies connect science with history, culture, and ethical considerations, making them powerful contexts for teaching the nature of science (NOS) as a human and socially embedded endeavor (Allchin, 2013; Matthews, 2015). Engaging with historical scientific mysteries may help pre-service teachers develop an understanding of science as a dynamic and evolving process, rather than a fixed collection of facts (Lederman et al., 2013). A limitation of the present study is that it did not include a hypothesis revision stage, which is widely regarded as essential for promoting sustained scientific inquiry and hypothetico–deductive reasoning (Lawson, 2009; NRC, 2012). Future studies should therefore provide pre-service teachers with successive evidence that allows them to revisit and revise their initial hypotheses, thereby more fully supporting the development of scientific reasoning.

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How Do Upper Secondary Greek Students View The Nature Of Science? The Case Of Chemistry

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Nature of Science (NOS) refers to science as a way of thinking along with the intrinsic beliefs and values related to scientific knowledge and its development. Taking into account the distinct and common characteristics of the different science disciplines, NOS is conceptualized as both general and domain specific. In this work, the views of Greek upper secondary school students regarding the different aspects of NOS were investigated, by taking the chemistry discipline as a characteristic case. An adapted version of the "Views of Nature of Science Questionnaire – Form C" (VNOS-C) instrument was employed and the responses of 96 students (16-17 y) were analysed qualitatively via the criteria of the VNOS Analysis and Scoring Rubric (VAScoR). A total of six NOS aspects were identified with students' views presenting a mixed picture regarding their VAScoR classification. For three NOS aspects - namely the myth of the "scientific method", tentative, and scientific theories – many partially informed views were identified. On the contrary, the naive views were a majority for the social and cultural embeddedness of science and with relatively frequent occurrence in the empirical and inferential NOS aspects. In addition, a quite large number of views regarding the empirical and inferential NOS aspects were classified as silent. The research findings provide insights into aspects of the chemistry curriculum and of the teaching approaches that need revaluation to enhance students' knowledge, skills and competencies with respect to the nature of science and promote chemical-scientific literacy.

Keywords: Domain-specific NOS, Domain general NOS, Nature of chemical laws

Introduction

Nature of science (NOS) has been an important educational objective for several decades and at the same time a significant topic in science education research. (Erduran et al., 2020; Abd-El-Khalick & Lederman, 2023). The discussion about the NOS construct among the research community and science educators, has provided several frameworks that aim to students' understandings of NOS for the promotion of scientific literacy. Several researchers have contributed to the conceptualization of NOS resulting in a set of some "general NOS aspects" or the consensus view of NOS (Abd-El-Khalick & Lederman, 2023). The term "consensus" should not be taken to imply full agreement on the framework. Although disagreements from a philosophical perspective and about the relations NOS with scientific inquiry or practices have largely been resolved, conversations about the "nature of NOS" still persist. These include critiques of the consensus view as being too general and arguments in favour of adopting domain-specific nature of science discipline, such as chemistry (e.g., Cetin et al., 2010).

According to the consensus framework, several lists that include a multitude of NOS aspects have been proposed. There exist, however, certain aspects, such as the empirical, tentative, creative, and scientific method, which are common in all lists (e.g. Lederman et al., 2002; Osborne et al., 2003), thus indicating that each one of these is related to a student's preconception about science (Kampourakis, 2016). These general NOS lists have been criticized as oversimplifying descriptions of science (e.g., Irzik & Nola, 2011). However, for school science, a simplified NOS view provides acceptable recommendations for NOS teaching and learning (Kampourakis, 2016).

An important discussion about NOS research which is considered crucial for secondary science education is related to the generality versus domain specificity of NOS. Some researchers have argued that 'the consensual general NOS aspects are too broad and do not capture the heterogeneity of science subjects (e.g., Irzik and Nola 2011). For instance, the different features of laws in different science disciplines are not conceptualized. Specifically, some laws in chemistry, like in physics, are quantitative in nature (e.g. laws of stoichiometry), but others rely more on approximations without possessing quantitative expression (e.g. the periodic law).

Based on science disciplines' similarities and differences, the domain-general and domain-specific approaches could be considered as complementary (Kampourakis 2016). Therefore, general NOS aspects could provide a foundation for further development of domain-specific NOS learning in school science and further research on domain-specific NOS assessments is needed.

The inclusion of NOS in science curricula together with the increasing interest in corresponding science education research resulted in the development of various NOS assessments, which can be divided into two types: forced choice and open-ended. The theory driven forced-choice instruments are constituted of items along with their answers derived from various theoretical perspectives (Aikenhead et al., 1987). Therefore, students' responses might be biased toward one philosophical view and consequently not accurately expressing their thoughts (Abd-El-Khalick & Lederman, 2023). During the last two decades there has been a shift from forced choice to open-ended instruments with the Views of Nature of Science (VNOS) questionnaire being one which has been widely used (Abd-El-Khalick & Lederman, 2023).

There are, however, various concerns about the use of open-ended instruments. An analysis of responses is exhausting work that needs a thorough understanding of the NOS framework as well as more time and resources, particularly for large-scale studies. Moreover, the resulting data is not suitable for statistical testing of relations between various variables. Several researchers have proposed various ways to quantify responses to open-ended NOS instruments (e.g., Abd-El-Khalick et al., 2024, Burgin & Sadler, 2016).

The purpose of the present study is to investigate the NOS views of Greek upper secondary students by taking chemistry as characteristic case. The consensus view of NOS is used as theoretical framework to elicit and discuss students' NOS views as an attempt to combine both domain general and specific NOS views in an assessment. The study was guided by the following research question:

- How do Greek upper secondary students view the NOS in the context of chemistry?

Method

In this study, a descriptive qualitative approach was employed focused on measuring students' NOS conceptions based on the consensus framework in the chemistry context.

Participants

A total of 96 students of the 10th and 11th Grade (16 – 17 y) from one public school located in Athens (Greece) were participants in this study, using a convenience sampling procedure. The 10th grade students have been involved in chemistry courses for 3 years and the 10th graders for 4 years. Moreover, during chemistry courses they did not participate in any activity about nature of science. Students responded to instrument questions during a one-hour lesson of chemistry course.

Instrument

The instrument used (named VNOS-C-Ad and referring specifically to the chemistry discipline, Table 1) consisted of seven items and was an adaptation of the original VNOS–C (Lederman et al., 2002) questionnaire. The item of VNOS–C about the scientific laws was excluded from

VNOS-C-Ad because in chemistry courses students have been taught only the periodic law, which differs from others scientific laws. For example, the periodic law is not expressed mathematically as physics laws and the term "periodic" in the periodic law is not related to temporal periodicity as others scientific laws (Erduran, 2007; Scerri, & Worrall, 2001). The questions about organisms and dinosaurs of the original VNOS–C instrument were also excluded as they are related to biology. Finally, the items that relate creativity and imagination with experiments/investigations were excluded based on time limitation.

Table 1. The VNOS-C-Ad instrument.

1. What, in your view, is science?

2. What makes chemistry different from other disciplines, like philosophy?

3. What is an experiment?

4. Does the development of scientific knowledge require experiments?

If yes, explain why. Give an example to defend your position.

If no, explain why. Give an example to defend your position.

5. After scientists have developed a scientific theory (e.g., atomic theory), does the theory ever change?

If you believe that scientific theories do not change, explain why. Defend your answer with examples.

If you believe that scientific theories do change:

(a) Explain why theories change?

(b) Explain why we bother to learn scientific theories? Defend your answer with examples.

6. Chemistry textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

7. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal, that is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.

If you believe that science is universal, explain why. Defend your answer with examples.

Data Analysis

The content validity of data is established during the first step of the analysis, where the target NOS aspect/s of each item were defined according to the literature (Lederman et al., 2002; Abd-El-Khalick et al., 2024). Then, students' responses were analysed in order to identify elements that justify their views of the NOS aspect and were classified to 4 categories as either informed (I), partially informed (P), naïve (N), and silent (S) according to the criteria of the VNOS Analysis and Scoring Rubric (VAScoR) (Abd-El-Khalick et al., 2024).

Table 4. The categories coding schema of students' views classification adopted from Abd-El-Khalick et al. (2024).

Category	Criteria
Informed view (I)	All elements of the target NOS aspect are judged to be informed
Partially informed view (P)	Only a subset of the core elements of the target NOS aspect are judged to be informed; and responses on other elements of the target NOS aspect are silent
Naïve view (N)	Either some or all elements of the target NOS aspect are naively addressed
Silent (S)	No relevant or irrelevant or incomprehensible or without reliable categorization response.

Two of the authors analysed the same responses of ten students, compared their analyses, and resolved discrepancies with the consensus of all authors to establish inter-rater reliability.

Results And Discussion

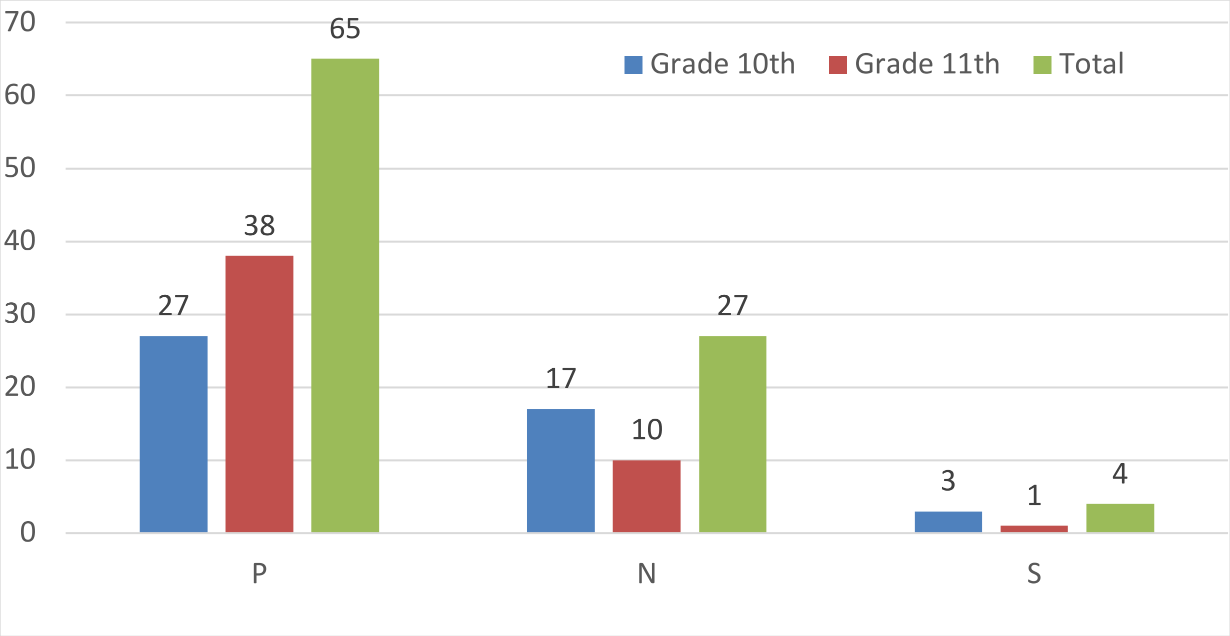
How Do Greek Upper Secondary Students View The Nos In The Context Of Chemistry?

Analysis of students' responses revealed the emergence of six NOS aspect/s: empirical, inferential, tentative, myth of "the scientific method", scientific theory, and social and cultural embeddedness of science.

How Do Students View Scientific Theories?

Students' views of the NOS aspect referring to scientific theories are mainly classified as partially informed (Figure 1).

Figure 1. Views of scientific theories aspect.



A representative quote showing a partially informed view is the following quote:

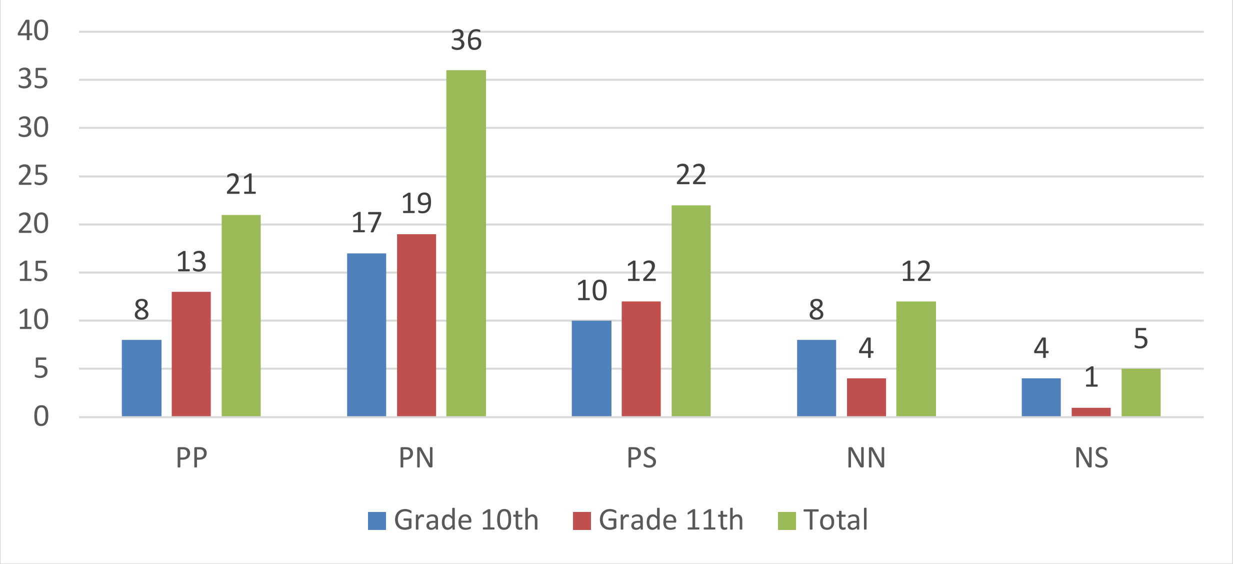
> Quote 1: "Since scientific theories have been confirmed using various means to prove their validity (e.g., microscopes for the structure of the atom), they are unlikely to change. They change if it is later proven, of course, that they are incorrect (this happens over time with the advancement of knowledge and technology)"

Do Students View Science As Tentative?

Students' responses to items 5 and 6 reveal the tentative NOS aspect and the distribution of their classifications are presented in Figure 2 (the first letter concerns the category of students' responses to item 5 and the second to item 6 respectively). The prevailing views in this case belonged to the category partially informed as 79 students express a partially informed view in at least one item. For example, students believe that conclusions arise from instruments (e.g., microscopes) rather than through reasoning (quote 2) Students with naïve views regard both scientists and the school curriculum as authoritative, containing absolute and unchanging knowledge about the physical world (quotes 3, 4)

> Quote 2: "Scientific theories change as scientific equipment improves. New tools allow for a deeper study of things, and as a result, sometimes the study uncovers new data that invalidate previous ones."

Figure 2. Views of tentative NOS aspect.



> Quote 3: "Scientists are very certain about the structure of the atom, as this theory has been proven to be true (through many experiments, other theories, and research) by previous scientists"

> Quote 4: "I believe they are quite certain (the scientists) for chemistry to be taught in schools."

As we can see in Figure 2, eleventh grade students also present more informed views than the ones in the 10th grade. Moreover, students' views of the tentative aspect seem to depend on the item.

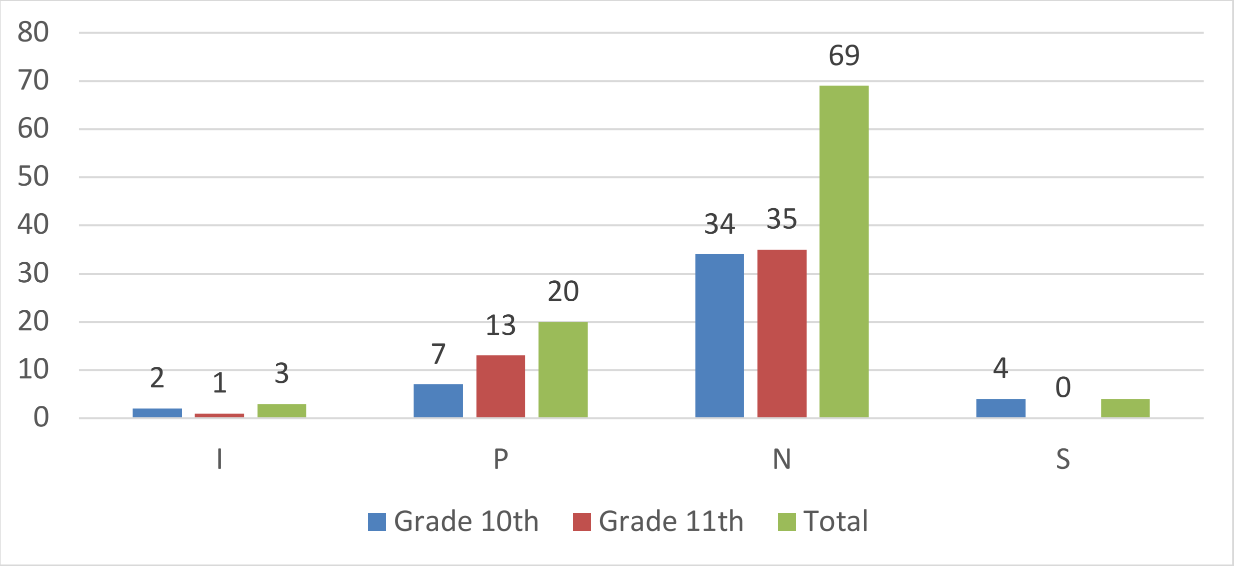
How Do Students View The Cultural Embeddedness Of Science?

Concerning the social and cultural embeddedness of science NOS aspect, 3 of the students' views are informed, 20 partially informed, and most of them (69) are naive views (Figure 3). Particularly characteristic examples of responses are presented by quotes 5 and 6.

Do Students View Science As Empirical And Inferential?

Figure 4 presents the classifications of students' views regarding the empirical (1st letter) and inferential (2nd letter) aspects. The views of the empirical NOS are classified as silent for most students (64), with the remaining students' responses being almost equally distributed between naive (15) and partially informed (17). Regarding the inferential NOS aspect most responses (67) are also classified as silent, 28 as naive and only one as partially informed.

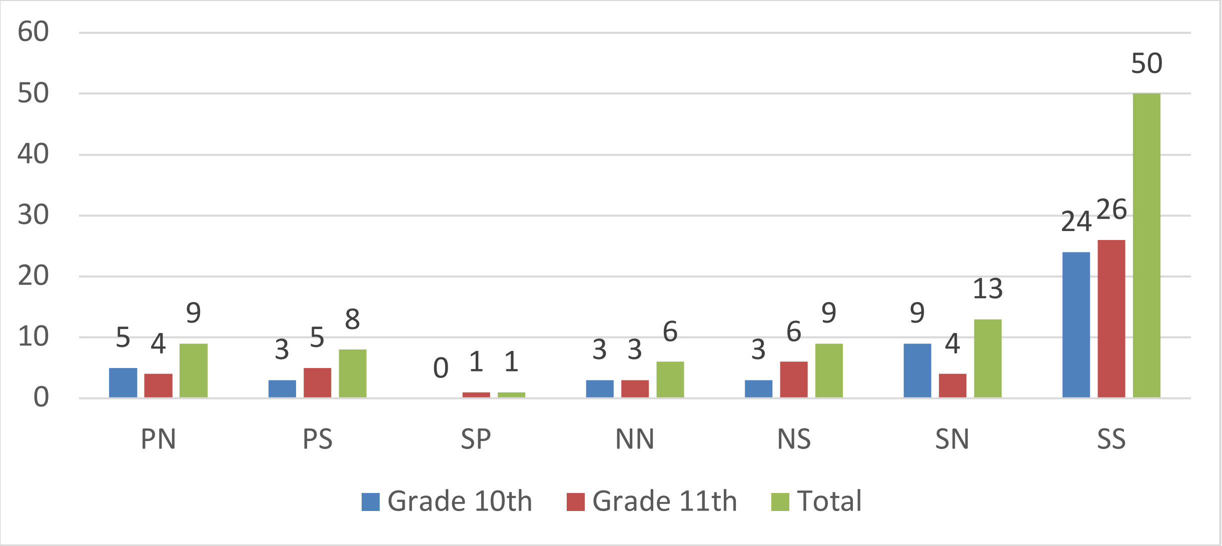
Figure 3. Views of social and cultural embeddedness of science aspect.



> Quote 5: "I believe that science reflects the values of the culture from which it originates because these values determine the conditions under which it will develop. For example, it is much easier to study and develop controversial scientific fields in a progressive country than in a religion - centered country" (partially informed view).

> Quote 6: "Science is universal, since we all live in the same space governed by the same physical and chemical laws. For example, atomic theory cannot be different in Europe and different in Asia because the culture and society are different" (naïve view).

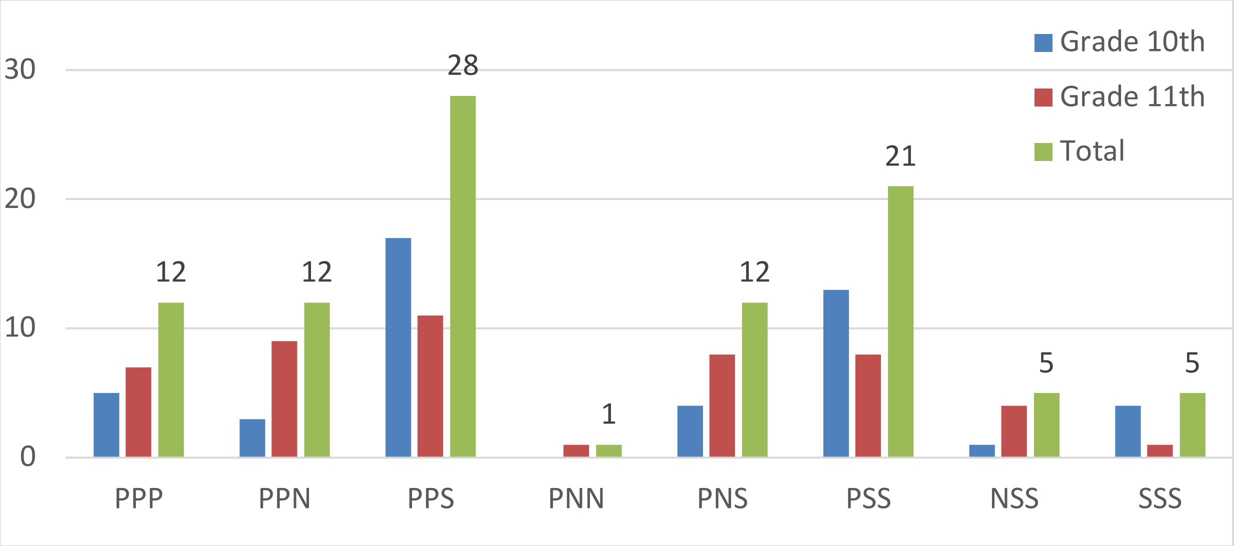
Figure 4. Views of empirical and inferential aspects.



How Do Students View "The Scientific Method"?

The myth of "the scientific method" aspect emerged from items 2, 3, 4 and the distribution of the classifications of students' views are presented in Figure 5. The first letter concerns the category of students' responses to item 2, the second to item 3 and the third to item 4, respectively.

Figure 5. Views of myth of "the scientific method" aspect.



Twelve students had consistent partially informed views (PPP), 40 students showed partially informed views in two items, and 31 students were silent in two or three items.

Interestingly, 11th grade students presented a shift to more informed views regarding the myth of “the scientific method”, tentative, scientific theories as well as social and cultural embeddedness of science aspects (Figures 1-5).

Conclusions

This study used the example of chemistry as a specific science discipline to investigate Greek upper secondary students’ NOS views. Six general NOS aspects were elicited from students’ responses. A variety of classifications of students’ views depending on the NOS aspect were revealed. Concerning the myth of the “scientific method”, tentative, and scientific theories NOS aspects most students’ presented partially informed views. On the contrary, the naive views were a majority for the social and cultural embeddedness of science and with relatively frequent occurrence in the empirical and inferential aspects.

This difference could be partially explained based on the Greek chemistry curriculum. Students are taught three models of atomic structure that were developed during different historical periods. Therefore, the example of atomic theory helps them express partially informed views regarding the “scientific method”, tentative, and scientific theories NOS aspects.

Many students’ responses regarding the empirical and inferential NOS aspects were irrelevant or incomprehensible and were classified as silent views. This indicates that traditional lab work in chemistry teaching is not sufficient for achieving meaningful NOS learning. Moreover, it could be related to the reduced students’ ability to express their conceptions in writing in an open-ended instrument.

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Arguing With Eugenics: Brazilian Reasoning About Inheritance In The Late 1920s

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This work contributes to the promotion of scientific literacy focused on social transformation by analysing conceptual and epistemic aspects of Brazilian eugenics. To this end, we present a documentary analysis of the first year of the Boletim de Eugenia (Eugenics Bulletin), one of the documents used to promote eugenics in Brazil. The analysis focus on how the conceptual and epistemic aspects are mobilized to support eugenics ideas. In our findings, concepts such as inheritance are central to justifying eugenics artificial selection but the reasoning is flawed. We argue that the historical case of eugenics is fruitful in science education for raising discussions on how science is not a neutral endeavour and in promoting scientific literacy focused on social transformation. Eugenics case allows discussing science as a social endeavour, highlighting ways to produce, evaluate and legitimize scientific knowledge, as well as the discussion of social and ethical limits of scientific knowledge.

Keywords: scientific literacy; history of science; scientific argumentation.

Introduction

Valladares (2021) claims Scientific Literacy (SL), from an emancipatory perspective, can be understood both as a social practice and as a tool for the self-construction of one's voice and place in the world. Students educated from this perspective should be committed to social transformation and capable of taking advantage of science and other cultural knowledge - being aware of science's potentials and limitations - in the generation of adaptative, resilient, and sustainable responses to the challenges of the twenty-first century (Valladares, 2021). Accordingly, this contemporary perspective of SL takes cultural pluralism into consideration, is oriented toward social transformation (Valladares, 2021; Guerrero et al., 2025), and is committed to social activism, realized through students' participation and emancipation (Valladares, 2021).

As highlighted above, the social activism proposed in this framework seeks to address the multiple systemic and structural forms of violence that violate human rights on a global scale in the twenty-first century, a context marked by a profound human, political, and environmental crises. However, these crises do not affect society uniformly, as oppressive structures (mainly racism, sexism, and classism) exclude certain minoritized social groups in favour of dominant ones. We agree with the arguments portrayed by Valladares (2021) and Silva and Sasseron (2021) regarding the importance of Science Education in helping us understand how differential access to science and the unequal consequences of the scientific enterprise perpetuate historical inequities, and how the production of scientific knowledge must be oriented toward reducing these disparities.

According to Guerrero et al. (2025), SL constitutes a "transformative and socio-ecojustice-oriented framework that moves beyond content knowledge and scientific competence to foster political agency, eco-reflexivity, and collective action" (Guerrero et al., 2025, p. 2). Thus, SL for social transformation highlights the importance of addressing socially relevant issues that enable the problematization of social injustices and inequities that are, to some extent, connected to science. Therefore, Science Education must address scientific laws and concepts allied with discussions about social scientific issues, as well as the epistemic, social, and material aspects of scientific knowledge (Silva & Sasseron, 2021). Considering ideas discussed by Duschl (2008) and Stroupe (2015), conceptual aspects are the knowledge developed by the scientific community; epistemic aspects are the criteria and norms used by scientists to determine what they know and why they know it; social aspects are the social processes by which scientific knowledge is produced, represented, and discussed; and the material aspects as the tools and technologies, along with their mode of use, applied in scientific investigation. This formative goal of SL, which goes beyond traditional content knowledge, can be achieved through different teaching approaches in which students engage with the social practices of science and, in doing so, learn about science (Silva & Sasseron, 2021). Guerrero et al. (2025) complement this discussion highlighting the importance of cross-disciplinarity and history-philosophy-sociology of science (HPSS) perspectives in the promotion of SL, especially of the critical and transformative aspect of it.

The use of History, Philosophy, and Sociology of Science (HPSS) in Science Education has long been recognized as a valuable means of presenting science as a form of knowledge that is socially produced and embedded in historical, social, economic, and political contexts (Allchin, 2013; Allchin et al., 2014; Forato et al., 2011). In this sense, numerous studies argue that HPSS can promote teaching about science, often referred to as the Nature of Science, converging to the transformative SL. However, the political and social inflections are still not explicit in this traditional justification to the use of HPSS in teaching. Moura (2025) recently pieced together proposals of a sociopolitical turn in Science Education that converges to SL for social transformation and recent literature has increasingly advocated for more politicized and politicizing uses of HPSS in Science Education.

For example, Moura (2021) discusses the potential of the use of HPSS to address historical processes of epistemicide, the plundering of knowledge, and the erasure of contributions from certain groups due to classist, racist, sexist, and colonial structures of oppression in the context of Science Education. He proposes it can be used to repair these harms since it unravels marginalized figures and suppressed forms of knowledge that can then be highlighted in Science classrooms. Similarly, Guerra and Moura (2022) propose expanding the traditional meanings of humanization and contextualization typically associated with HPSS in Science Education. Drawing on History of Science, they argue that, beyond being a human endeavour, science was produced in a global context by people of diverse origins and ethnic backgrounds and advocate that this should be highlighted in Science Education to expand student's perception of who can make science and from what places they come from. They also argue that it is important to problematize in Science classrooms that many of these contributors had their work erased due to the entanglement of modern science with colonialism, patriarchy, and capitalism. Both proposals for sociopolitical turn in HPSS (Moura, 2021 and Guerra & Moura, 2022) converge in their use of HPSS to problematize and repair the colonial erasures produced by modern science. In other words, they articulate HPSS as a pathway for promoting decolonial education in Science Education, and to foster antiracist approaches in Science classrooms (Pinheiro, 2023).

Once modern science has not only reproduced but also helped establish and justify racist and colonial power structures – such as through the development of race as a biological concept, social Darwinism, and eugenics – we argue that it's important that Science Education community investigates these historical episodes, so they can be discussed within an antiracist, justice-oriented and transformative SL framework. To contribute to this end, this paper examines a major journal on eugenics from the late 1920s in Brazil. The aim of this work is to analyse inconsistencies in the mobilization of conceptual and epistemic aspects of science to support eugenic ideas in Brazil in the early 20th century and map the implications to Science Education.

Eugenics As A Case Of History Of Science

Eugenics was coined in 1883 by Francis Galton (1822-1911) in England, after he and other colleagues had been discussing the "problems" with migration and the poor classes of London. The movement proposed that the "improvement" of the human race (Singleton, 2014) could occur by promoting the perpetuation of traits deemed "superior" and restricting the transmission of traits associated with supposedly "inferior" individuals (Santos et al., 2014). Emerging during the period of disciplinary consolidation of modern science, eugenics held scientific status for decades (Diwan, 2007) and perpetuated racism as a result of the difference of races (biological at that point). To define which traits were desirable, the definitions were rooted in the English elite bias and were marked by racist assumptions (Zuberi, 2023). This framework ultimately reinforced hierarchical classifications of human groups and exclusionary policies of reproductive control.

Galton formulated eugenics as a way of justifying and addressing the social problems confronting the nineteenth-century English industrial bourgeoisie (Góes, 2015). Working-class neighbourhoods suffered from intense poverty and its associated social challenges. Galton attributed biological origins to behaviours, naming poverty, delinquency, prostitution, and mental illness, as the acts of "degenerate" people, arguing that physical, intellectual, moral, and psychological traits were hereditary (Góes, 2015). Galton claimed that the recent concepts of evolution could "help" eliminate the "degenerate" individuals and improve the species. In this sense, discussing eugenics might be fruitful to promote discussions about the goals of science as a potentially biased enterprise.

Today, we understand eugenics ideas are indefensible, still they were pervasive to the point of guiding public policies in various countries (Goés, 2015). One of the most known influences of the eugenics movement was the Nazi regime, with it's genocide practices (Stepan, 2005). In the United States, the eugenics movement developed a specially radical aspect, marked by segregation and sterilization laws and practices (Singleton, 2014). In Brazil, we highlight racist immigration policies that, in the beginning of the XX century, intended to minimize the immigration from non-European countries, and maximize the European "stock" aiming at whitening the population (Nascimento, 2016). Besides that, Brazilian federal constitution of 1934 explicitly advocated for a eugenic education in its Article 138, subsection (b) (Brazil, 1934).

In general, eugenics reasoning included i. the identification of "normative" individuals or individuals arbitrarily considered inferior; ii. the classification of individuals into groups according to shared characteristics (phenotypic or moral/behavioral); iii. the hierarchization of these groups; and iv. the symbolic or physical exclusion of groups considered inferior from the process of reproduction (Miranda, 2025). Despite these general aspects that characterize eugenic reasoning, eugenic ideas presented themselves in specific contours depending on the contexts in which they were produced and appropriated (Góes, 2015), therefore the eugenics movement cannot be treated or investigated as universal or uniform.

Eugenics ideology continues to influence practices in current society to the extent of possible uses for DNA and heritage exams, genetic counselling, artificial insemination, fertility control policies, and the persistence of the biologisation of social relations in research within the field of psychology on human behaviour (Góes, 2023). That's why Science Education should address and problematize eugenic ideas, then students become able to participate in the social debates regarding themes, either directly or indirectly, related to eugenics. Therefore, we argue that it is important that Science Education research analyse how the conceptual and epistemic aspects of science were mobilized to support eugenics so that we can help students criticize similar ideas that may rise in current days and prevent the reinforcement of eugenics and deterministic reasoning through Science Education.

Methods

The research approach adopted was qualitative, prioritizing an in-depth analysis of a phenomenon (Creswell & Creswell, 2023), in this case, the ways in which conceptual and epistemic aspects were inconsistently mobilized to support eugenic ideas in Brazil. This study is characterized as documentary research, which aims to contribute to the understanding of a community or phenomenon situated in a specific time and place (Fontana & Pereira, 2023).

We selected texts from the first year of the Eugenics Bulletin (Boletim de Eugenia – BE), a journal designed by Renato Kehl that circulated in Brazil between 1929 and 1933, disseminating and promoting eugenics in the country. The journal included thematic sections related to politics, education, manners, science, and health, which sought to legitimize eugenics as a scientific field of study. The BE had a central role in introducing eugenic reasoning in Brazil and its future ramifications (Maciel, 1999; Góes, 2015). The texts were accessed electronically through the Brazilian Digital Newspaper Library (Hemeroteca Digital Brasileira).

For the analysis, we selected all articles published in the 1929 issues of the BE available at the repository, a total of 105 articles. Initially, we conducted a full reading of the articles, identifying excerpts that evidenced the inconsistent mobilization of conceptual or epistemic aspects of the Natural Sciences to justify eugenic ideas disseminated in the BE. The presence of disciplinary concepts in the excerpts was used as cue to conceptual aspects, while epistemic aspects were identified through the presence of scientific or purportedly scientific arguments. Each article was analysed by at least two of the authors.

Following the initial survey, 28 articles were selected in which the arguments presented contained conceptual errors, and logical or material inconsistencies. We did not consider arguments in which the concepts were mobilized correctly, since the focus of the analysis is on the misuse of science to support eugenic ideas. The evaluation of the correctness of concept usage took into account the scientific standards of the period, in order to avoid anachronistic analyses. As the final step in constructing the analytical corpus, we selected, from the 28 articles, only those in which the mobilized biological concepts were in some way defined or exemplified in terms of their application. This resulted in a final selection of 20 articles.

Finally, the conceptual and argumentative inconsistencies were made explicit in a descriptive-argumentative text, interspersed with excerpts from the BE that illustrate these inconsistencies, forming the basis of our results and discussion. These stages were carried out by a group of six researchers in the field of Science Education, aiming at validating both the construction of the corpus of analysis and the analytical process.

Results and Discussions

According to the BE, eugenics is a science that aims

> [...] to cooperate for the progressive increase of physically, psychically and morally healthy men; for the gradual reduction of the contingent of the weak, sick and degenerate, thus contributing to the constitution of [...] in short, a balanced humanity, composed of strong and beautiful individuals, elements of peace and work (Kehl, 1929, n.4, p. 1, translated from Brazilian Portuguese - BP).

As published, the purpose of eugenics is to promote an alleged improvement of the human species through selecting individuals who are deemed to be “well-endowed”, “superior” or “eugenic”.

The **biological concepts** identified in the BE's articles were heredity, inheritance, artificial selection, and natural selection. These are crucial concepts to eugenics. In some excerpts, the BE explicitly acknowledges eugenics as a process of **artificial selection**:

> Who doesn't know what crossbreeding and seed selection mean for a plant? I have seen forests of fantastic beauty in Brazil [...] but their orchids were not as beautiful as the orchids that, through artificial selection, acquire truly extraordinary form and development in Brazilian gardens. [...] These selective practices are applicable to the human species. It has been proven that crosses between superior breeds produce superior types, and vice versa (Recasens, 1929, n. 4, p. 2, translated from BP).

Here we highlight the subtlety in suggesting artificial selection as a tool for “improving” the human race. Although the word “artificial” is not directly used, the expression “selective practices” is used in a synonym meaning, as it suggests selective breeding, that was inflicted by the eugenics movement through the control of human reproduction or killing.

Artificial selection is presented as a solution to the alleged inability of **natural selection** alone to contribute to the improvement of the human species. The defence of this idea becomes evident in the following excerpt: “*It [eugenics] will do everything in its power to halt reverse biological selection in contemporary society, and everything that may serve to support the vigorous natural selection that so actively contributes to the preservation of the most capable*” (“*eugenia e alcoolismo”*, 1929, n. 8, p. 5, translated from BP). Francis Galton, proposed similar ideas in the first book in which he uses the term “eugenic”. According to him, in civilized societies, humanity does not experience the effect of natural selection the same way:

> His [“man’s”] character is exceedingly complex, even in members of the simplest and purest savage race; much more is it so in civilized races, who have long since been exempted from the full rigor of natural selection, and have become more mongrel in their breed than any other animal on the face of the earth (Galton, 1883, p. 178).

In addition to proposing **artificial selection**, the BE also provided indications of how to implement it, in articles such as *The Selection of the Well-Endowed* (Decroly, n. 10, 1929). Also, **artificial selection** is closely related to the importance given to inheritance since these texts emphasized the importance of considering the role of **heredity** and environment in determining individual superiority, so that the most “fit” could be selected (Decroly, n. 10, 1929). Similar discussions are found in the chapter *Nurture and Nature* by Galton (1883). This implies that both in Brazil and England discussion on the relative importance of the environment and inheritance in determining people’s characteristics were relevant to the eugenics movement. Differences rise though regarding the emphasis given to each factor in each context. In both cases, we observe the attribution of great importance to inheritance, once to be selected characteristics must be inheritable. Although in Latin countries, in general, a little more relevance is given to the environment (Stepan, 2015). Because of the ethnic constitution of Brazil, it would not be possible to prevent races deemed inferior from reproducing. As a result, in Brazil, interracial reproduction arises as a eugenics strategy (Góes, 2015) and there is an overlap between eugenics (focus on inheritance) and hygienism in Brazil (focus on bettering the environment) (Maciel, 1999).

Recognizing that eugenics proposed artificial selection is important for two reasons. First, it reveals the arbitrariness underlying eugenics, manifested in the fact that “good” characteristics – those considered to make individuals more suited to civilization – were selected arbitrarily rather than in relation to the natural environment, as proposed in Darwinian evolutionary thought.

Second, artificial selection is the reason why such importance is given to **heredity** and **inheritance** in eugenics reasoning. According to the BE, the aim of studying biological inheritance would be "*discovering the laws of inheritance and consciously applying them to the improvement of human offspring*" (Huerta, 1929, n. 8, p. 2, translated from BP). In other words, eugenics sets out to study the inheritance of characteristics, so that they can then be selected.

The primary importance attributed to **heredity** is further justified by the fact that, within eugenics reasoning, heredity was responsible for the continuity of characteristics across generations, whereas differences between one generation and another were understood as a result from environmental influence: "*This does not mean, however, that our personal influence is null. Far from it, I think, the action of the environment and education can be enormous. Indeed, alongside the continuity of characteristics over time (heredity), there are also differences*" (Govaerts, 1929, n. 1, p. 4, translated from BP). This way of mobilizing **the role of the environment in the evolutionary process** differs from that proposed by Darwinian evolutionary thought at the time, which conceived the environment as a filter for existing variations rather than as a generator of disturbance and difference. Nevertheless, this concept was mobilized in such a way to justify the importance of identifying which inheritable characteristics should be selected.

In our analysis, we identified several articles that discussed whether certain characteristics were inheritable or not, including criminality, epilepsy, haemophilia, alcoholism, violent behaviour, docility (individuals considered amenable to education), and aptitude for specific sports, forms of art, or professions. These characteristics were pondered as parameters for **artificial selection**. Similar discussions can be found in the chapter *Criminals and the Insane* by Galton (1883). In both the BE and Galton's book the claimed inheritability of characteristics such as criminality and alcoholism is used to justify the control of human reproduction as social improvement. The biologisation of such human behaviours culminates in the naturalization of the social injustices that contribute to these behaviours.

Regarding the argumentative problems identified in the analysed arguments, there are inconsistencies such as the **presentation of a conclusion without evidence**, such as in "*This is why education comes up against, powerless, in many cases, failing to tame an untamed person, whose constitution is the result of an irremovable hereditary process. 'One is born good!'*" (Kehl, 1929, n. 9, p. 1, translated from BP). In the excerpt, the argument is made that not all individuals should be educated, based on the premise that some people are biologically undomesticable; however, no evidence is provided to support this claim. Also, this excerpt asserts that 'domesticability' is an inheritable characteristic, without defining what 'domesticability' is or presenting any evidence.

Other arguments are based on **confounding correlation for cause**:

> An investigation was carried out among 3000 English criminals in London prisons. With the help of Galton's correlation coefficient, Dr. Goering organized the similarity indices between criminals linked by kinship, coming to the conclusion that heredity plays a preponderant role in the transmission of these characteristics (Kehl, 1929, n. 5, p. 3, translated from BP).

The co-occurrence of two variables, in this case kinship and criminality, is taken as proof of a causal relation between the two variables, culminating in the conclusion that the characteristics are hereditary. In other words, if a father and son are both criminals, criminality is hereditary, and the son inherited his criminal inclination. The same type of argumentation is found in the chapter *Criminals and the Insane* by Galton (1883). This highlights the biologisation of social behaviour as an agenda of the eugenics movement both in Brazil and England. Besides, it demonstrates that, in both cases, political agendas took precedence over scientific rigor in the construction of the arguments. This type of argument is presented for physical and moral characteristics, whether they are perceived as good or not:

> Mack Garner, a champion horse racer [...] tells an interesting story about the tendency of all the members of his family to pursue this profession. His father and grandfather were both jockeys [...] His four brothers were dedicated to the sport [...] One of his nephews is already a jockey and the other two, while still children, already have a special interest in everything to do with horses (Kehl, n. 10, 1929, p. 4, translated from BP).

It is also worth noting that none of the arguments present **alternative hypotheses** or **methodological details on how the evidence was gathered**, which is expected for validating reliable scientific claims. The only material aspect of the mode of production of scientific knowledge mobilized in the argument is the use of statistical data, employed in an anecdotal manner and insufficient to support the following conclusions. Thus, conceptual and epistemic aspects cannot be analysed separately, since arguments are responsible for guaranteeing that the way in which the concepts are produced, mobilized and used to draw conclusions is valid. This result reinforces the importance of taking this entanglement between the mobilization of epistemic and conceptual aspects to the context of Science Education.

Conclusion

Brazilian eugenics reasoning lacks evidence to justify its claims. Still, it sustained a myriad of discriminatory political and social actions and promoted a racist ideology. Brazilian eugenics used science to fulfil an agenda and the arguments or concepts used didn't even need to be sound for that, extrapolating disputed concepts for every convenient characteristic that could be used against non-white and poor people. Our analysis helps us understand that conceptual and epistemic aspects are not in a vacuum, and the ideas in the BE were the needed framework to legitimize elite's discrimination.

As we focused in the Brazilian context, the results of this study cannot be generalized as applicable or true to the eugenics movement in different countries. However, we identified some resemblance between Brazilian and English eugenics, from themes of study, theoretical propositions and premises to argumentative inconsistencies observed. Thus, we propose that Science Education research could benefit from further research regarding the conceptual and epistemological use of science to justify eugenics in different contexts. By doing so, we will be able to trace general aspects of these appropriations, revealing similarities among countries, and differences due to specific contexts and interests of each nation.

Despite the regionalized aspect of the analysis presented in this paper, we understand that some of the results allow the discussion of broad implications to the field of Science Education. First, we argue it would be fruitful to use the historical case of eugenics in the context of SL for social transformation, as the eugenics movement illustrates the social consequences of a biased and elitist scientific production allowing the discussion of the importance of a diverse scientific community to guarantee scientific objectivity. Second, we propose the use of the historical case of eugenics also makes it possible to discuss social aspects related to the production of scientific knowledge, showing that scientific production is not neutral, but a human production located in a historical and cultural space, producing and being influenced by the values in force in society (Silva & Sasseron, 2021). Third, we understand the historical case of eugenics highlights the importance of discussing the need of ethics and bioethics in science in science classrooms.

Regarding other implications to Science Education, we highlight the importance of promoting a historicized teaching of genetics and evolutionary biology. We understand that discussing the eugenics movement could collaborate to the construction of a more complex and critical comprehension of the Nature of Science and of the role of science in society. Besides that, we argue for the importance in promoting a biology teaching that intentionally seeks to prevent the construction of deterministic ideas that align with eugenic reasoning and a teaching about evolutionary biology that differentiates biological evolution from biological or even social supposed improvement that is also a eugenic idea. We also believe that the poor scientific argumentation identified in the BE could be used to discuss what counts or doesn't as scientific evidence and how to build valid arguments. These skills are very important within a SL for social transformation framework.

In summary, the characteristics of eugenics highlighted by the analysis presented in this paper demonstrate the Historical case of eugenics is interesting to promote SL to social transformation since it allows the discussion of social political aspects related to science, either in an internalist manner - what counts or does not count as science, diversity in academia, ethics - or an externalist one - the social and historical character of science and the possible social consequences of scientific production.

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Heritage And Transmission: A Reflection On The Origins And Development Of Didactics Of Science/Science Education Research

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The French journal RSDT-Recherches en Didactique de Sciences et des Technologies opened a call in 2025 to recruit contributions to reflect on the origins and development of the research field of didactics of science in France. It is 40 years since the first publication of the journal Aster, the first French journal for research in didactics of experimental sciences. This call, the 30th anniversary of ESERA, and the recent foundation of ESERA SIG9 on Histories of Science Education constitute an opportunity to start a shared reflection on the history of didactics of science/science education research. A general introduction for the western world and three cases from France, Luxembourg and Catalonia-Spain are presented focusing on the emergence of the field at either the country or the institution level. The aims of the symposium presented here are the following:(a) situating the origins of didactics of science/science education research in the context of the western world; (b) identifying the thematic changes in research programs during these years in different contexts. This paper concludes with a discussion on the commonalities and divergences arising from the drafting of a history of didactics of science/ science education research in the context of the countries represented -France, Luxembourg and Catalonia-Spain.

Keywords: Histories of Science Education, History of Didactics of Science, Case Studies.

Introduction

The French journal *RSDT-Recherches en Didactique de Sciences et des Technologies* opened a call last year to recruit several contributions to reflect on the origins and development of the field of research of didactics of science in France (Lhoste and Venturini 2025). It is 40 years since the first publication of the journal *Aster*, the first French journal for (scientific) research on didactics of experimental sciences. Such calls, in addition to the 30th anniversary of international association ESERA and the recent foundation of ESERA SIG9 on Histories of Science Education, constitute an opportunity to start a shared reflection on the history of didactics of science/science education research in different western countries, focusing on countries, institutions, research groups or individual researchers. The first aim of the symposium presented here was to situate the origins of didactics of science or science education research fields in the context of the western world through the following question: What have been the themes, the academic fields, the people, and the research groups that have contributed to the birth of our discipline in different western countries or institutions? The second aim of the symposium was to conduct an audit of the first results considering thematic changes throughout the years in different contexts. The question guiding this reflection has been the following: In what ways have the research questions, research approaches and results changed over these years in different western countries? The symposium discussed in this chapter was promoted by the recently created ESERA SIG9 Histories of Science Education, and we hope it will open the door to conduct more systematic historical inquiry within the science education research community worldwide.

The Emergence And Development Of Research In Didactics Of Science In The Years 1970-2000: A Focus On The Western World And France

The first contribution of the symposium addressed the first aim by examining the emergence of research in the didactics of science across Western countries and, within this context, the development of this field in France. For the whole symposium, this contribution provides a common ground useful for the positioning of the other three contributions situated in France, Luxembourg and Catalonia-Spain.

Renewal Of Science Teaching

To analyse this emergence in relation to the renewal of teaching, our framework includes some social components: the societal and institutional contexts, the social status of the actors involved, their objectives, the way they work in groups and the nature of their productions.

Societal And Institutional Contexts

Beginning in the 1950s–70s, Western countries began to reflect on the massification of education, driven by policymakers, academic societies, professional associations, and society demands. In France, in the fields of sciences and mathematics education, the Academy of Sciences, along with associations of mathematics teachers and later, associations of physics-chemistry and life and earth sciences teachers advocated for renewing secondary education. The evolution of the science teaching at secondary school level, spurred by these initiatives, was influenced by ministerial decisions and shaped by the broader French educational context.

The Designer Groups: Institutional Anchoring And Activities

Groups combining research and development, often involving researchers and teachers, were formed. These groups produced teaching resources and research findings with a particular focus on understanding students' learning difficulties. In most countries, the groups responsible for designing new teaching resources became, sooner or later, affiliated with university institutions. For instance, in France, the Lagarrigue ministerial commission established a working group led by physicist Goéry Delacôte. A few years later, this group evolved into a research laboratory called LIREST (*Laboratoire Interuniversitaire de Recherche sur l'Enseignement Scientifique et Technologique*) associated with a university in Paris and the National Center for Scientific Research (CNRS). A defining feature of designer groups was their collaborative nature where researchers and teachers worked together to design teaching resources. During this period, researchers and sometimes teachers with initial training in physics or chemistry also studied psychology (e.g. Dewey, Piaget) and shared constructivist perspectives.

Contribution Of Activities For Renewing Science Teaching To The Emergence Of Research In Didactics Of Science

The work on students' conceptual understanding was clearly linked to the development of research in didactics particularly in the domain often called students' conceptions. In addition, although the theoretical component was not highly developed, several results were replicated across different countries (Driver et al., 1985). The question of whether designing teaching materials is a research activity was less clear. According to Cobb et al. (2003), in research, "design experiments are conducted to develop theories, not merely to empirically tune 'what works'. These theories are relatively humble in that they target domain-specific learning processes" (ibid, p.9). In this sense, designing teaching materials at this time may not fully qualify as research. However, it incorporated research elements such as analysing the nature of the knowledge taught and the teaching goals, paving the way for the emergence of research such as design experiments and design-based research.

In conclusion it is worth mentioning that government institutions and education systems, which initially supported the design of science teaching materials by designer groups affiliated with universities, some years later took the lead in modifying official curricula and planning. These changes were only partially nourished by the productions of the designer groups (French, 1986). Nonetheless, researchers involved in these productions and other researchers contributed to the creation of research associations, such as the European Science Education Research Association (ESERA) founded in April 1995 which remains active today.

Evolution Of Research Themes From Its Beginnings To The 2000S Based On ESERA Conferences

This presentation addresses the symposium's second aim with an analysis of the evolution of research themes from its beginnings to the 2000s, primarily based on the strands of the early ESERA conferences. This analysis is developed based on a generic structure, the didactic triangle with three poles, student, teacher, and teaching content and their interrelationships. This approach helps to put together research studies spread across the strands and highlights broader trends such as the decline in research on students' conceptions, the rise of studies on the nature of science, socio-scientific issues and science teaching practices in relation to enquiry-based learning. Beyond the triangle, two additional themes emerged: the first related to curriculum policy involving the education system, and the second focused on the state and the practices of research in science education. This brief analysis shows that researchers involved in developing teaching materials were also engaged - directly or through colleagues - in specific research themes. It also highlights that theorizing the activity of designing teaching resources requires more time probably because of the inherent complexity of teaching, the complexity of "learning ecology".

Case 1: The Origins Of Didactics Of Life And Earth Sciences In France: Groups, Institutions, Research Orientations

The first case is situated in the context of France and aims at looking back at the origins of a research discipline, the didactics of life and earth sciences in France in the second half of the 20th century. This contribution addresses the following themes and questions: (a) the key players in the emergence of this research discipline (Who are the protagonists in the emergence of this discipline? What are their functions? What are their intellectual filiations?); (b) the various institutions and contexts in which this early research took place (What groups contributed to the emergence of this discipline? What links are there with universities and academic research?) and (c) the first avenues of research explored by the first publications in the field of life and earth sciences didactics. (What are the initial research concerns? What avenues of research are opening? How are they unfolding?)

The Origins Of Life And Earth Sciences Didactics In The Pedagogical Reform Of The 1960S-1970S

The origins of the didactics of life and Earth sciences can be traced back to the pedagogical reform movements of the 1960s and 1970s (Kahn & D'Enfert, 2010). The central issue at stake was questioning of both the traditional school format and the organization of teaching. This critique of traditional education also involved a challenge to the empiricist and dogmatic vision of science education, which was prevalent in the "lesson of things" approach. As early as the 1960s, this challenge began to take shape in the pedagogical sphere (Kahn, 2000). This pedagogical reform led to the implementation of awakening activities in primary education (Best, 1973; Best, 2006). The first research in the didactics of life and Earth sciences was developed within the National Pedagogical Institute (IPN), led by Louis Legrand. In 1967, the field of educational sciences was established within universities, and in 1969, Legrand created a didactics department within the IPN, which included a "science section" (later renamed "experimental sciences"). Victor Host, an associate professor of natural sciences involved in teacher training at normal schools, was appointed by Legrand in 1969 to lead this section. The research efforts were driven by awakening activities at the primary school level and experimental lower secondary schools (CES).

The Development Of The IPN Science Team And Action Research

With the transformation of the IPN (Institut Pédagogique National) into the INRP (Institut National de Recherche Pédagogique) in 1976, Jeanine Deunf, an inspector general of national education, led teacher training programs for *écoles normales* (teacher training schools) at the national level, fostering the development of action research. Many *école normale* professors contributed to this research, as evidenced by the list of contributors to the study *Procédures d'apprentissage en sciences expérimentales* mentioned in the journal *Aster* in 1985, and later published in 1998 under the title *Comment les enfants apprennent les sciences* (Astolfi et al., 1998). A subset of Victor Host team—comprising Jean-Pierre Astolfi, André Giordan, Gabriel Gohau, Victor Host, Jean-Louis Martinand, and Georges Zadounaïsky—published the first didactics book in the field of science education in 1978: *Quelle éducation scientifique, pour quelle société?* (Astolfi et al., 1978). The book's first chapter, with the evocative title *OHERIC ne répond plus? Le naufrage de l'éducation scientifique ?* ("OHERIC is no longer responding? The shipwreck of science education?"), written by A. Giordan, directly challenged the empiricist approach to scientific methods in schools. This team was also responsible for launching the journal *Aster*, published by the INRP from 1985 onward.

A Gradual Integration Into The Academic Sphere

Initially, the emerging community of didactics researchers did not readily accept academic engagement. However, Victor Host encouraged such involvement and established connections with Georges Canguilhem, a philosopher of biology. This led to the creation of a *Diplôme d'Études Approfondies* (DEA, equivalent to a master's degree) in didactics, with a specialization in biology education, environmental education, and later geology, at Paris 7 University in 1975, spearheaded by Christian Souchon and Victor Host. The program initially enrolled two students, Michèle Dupont and Guy Rumelhard, both of whom later joined the faculty as educators in 1979. The establishment of the *Instituts Universitaires de Formation des Maîtres* (IUFM) in 1991 facilitated the creation of the first faculty positions dedicated to research and teaching in life and Earth sciences didactics.

Research Themes

The foundational research themes in life and Earth sciences didactics emerged from the early work conducted at the IPN under the direction of Victor Host. Jean-Pierre Astolfi (2008, pp. 103–104) outlined the core issues that structured the initial research in this field: (a) The constant avoidance of verbalism and dogmatism; (b) The role of scientific attitudes; (c) The necessity of anchoring educational practices in children's spontaneous needs; (d) The importance of listening to students in order to understand the logic of their thinking; (e) The impact of students' conceptions of scientific knowledge on their future learning; (f) The requirements of conceptualization; (g) The diversity of levels of scientific concept formulation; (h) The construction of observational frameworks; (i) The central role of scientific problems; (j) The organization of scientific disciplines around a limited number of structuring paradigms; (k) The significance of the history and epistemology of science in addressing didactic challenges; and (l) The importance of written and graphical records in constructing scientific thought, distinguishing between the logic of discovery and the logic of communication.

Case 2: The Emergence Of Didactics Of Science As A Research Field At The Universitat Autònoma De Barcelona

This case aims at situating the origins of the Didactics of Science field at the Universitat Autònoma de Barcelona (UAB) in Catalonia, Spain, from the point of view of the actors participating in its emergence between 1970 and 1995. In the past, there have been several efforts to construct the history of science education research through different narrative approaches (Adúriz-Bravo and Izquierdo 2001; Fensham 2004). The work of Tobin and Roth (2007) is particularly useful for this contribution since they conceptualize the history of the field through the lenses of cultural sociology. The overarching methodological approach used in this contribution is compatible with autoethnography understood as both process and product (Ellis, Adams and Bochner 2011). This approach to research and writing seeks to describe and systematically analyse personal experience to understand cultural experience. The product is a collective narrative co-written by the three co-authors through an ongoing participatory process initiated in 2020. This process has involved a diversity of actors including students, retired professors, and active members of the Didactics of Mathematics and Experimental Sciences Department from UAB. The narrative is organized into two sections: (a) First phase (1970-1985) characterized by the growth of science teaching innovations and the institutionalization of science teacher education, and (b) Second phase (1985-1995) constituted by the processes and actions undertaken to become researchers in didactics of science.

Promoting Science Teaching Innovations And Science Teacher Education (1970-1985)

Spanish political context has always strongly influenced innovation in education as well as science education in Catalonia. Previously to the Spanish civil war starting in 1936 and during the Catalan Republic there was a strong political support to educational innovation based on the progressive ideas coming from continental Europe. These innovations were suddenly interrupted, strongly repressed and innovative schools closed during the dictatorship. Despite these difficulties, during the dictatorship, young teachers created new primary and secondary schools conducting innovations in science teaching. The three co-authors have been science teachers or students at these schools and participated in science teachers' groups with the aim of promoting teaching innovations. Several key Catalan institutions played a very important role in promoting and sustaining these *innovative science teachers' groups*. An example at the primary education level was the "Working Group for the Teaching of Science" hosted by Rosa Sensat Teachers Association and another example at the secondary education level was the "Didactics Center of Experimental Sciences" hosted by Col.legi de Doctors i Llicenciats.

Networking and internationalization were important factors influencing the emergence of our field at UAB. The first Spanish conference we ever participated was the I Simposium Internacional de Didáctica General y Didácticas Especiales held in la Manga del Mar Menor, Spain, September 27th-October 2nd, 1982. The first international conference we ever participated was the Journées Internationales de Chamonix, France, in 1987 (Sanmartí 1987). Both countries, UK and France, have been very influential on the emergence of our field in Catalonia and Spain. Finally, the *university status of science teacher education* became possible because of the General Education Law of 1970. Two years later it was founded the Escola Universitaria de Fromació del Professorat d'EGB at UAB, also known as Teachers' School of Sant Cugat, with the impulse of very committed and innovative science teachers, devoted to the training of infant and primary teachers and without research functions (Angel, Pujol & Villanueva 2020).

Becoming Researchers In Didactics Of Science (1985-1995)

The *capacity to conduct research by science teacher trainers* was not consolidated until 1983 with the Law of University Reform, the first after the dictatorship, that regulated the creation of new fields such as Didactics of Experimental Science and the departments that would cultivate them. The challenge of our field at UAB at this point was to gain research competence in Didactics of Science in a very short time. The training of researchers in didactics of science had two targets: science teacher trainers and innovative science teachers. They could only get a UAB doctorate in pure sciences or in general pedagogy. The role of Mercè Izquierdo as a policy maker in the Catalan Government in 1985 was crucial to organize and fund the international doctoral training of UAB science teacher educators as a group through the collaboration of the Chelsea College at the University of London.

The *first research tool created at UAB* in our field was the Spanish research journal, *Enseñanza de las Ciencias*, born in 1983 at UAB. In the editorial of the first number, a concern was expressed on the difficulties of producing quality educational research, and the lack of publications authored by Spanish researchers in international journals. In 1985 the first Spanish conference I *Congreso Internacional de Investigación en Didáctica de las Ciencias* took place at UAB in Bellaterra (Barcelona) and was organized by the previously created journal, the UAB and Universitat de Valencia. Both the journal and the conference had a national and international scope and have been active since then.

The *first research themes* of the innovative science teachers focused mainly on laboratory work and students' ideas. Once the university department was created and funding was necessary, the research themes evolved towards the following: (a) Evaluation for science learning (approaches, tools); (b) Modelling in School Science (Philosophy of Science, Language, Context); and (c) Environmental Education.

Case 3: Primary Science Education Research in Luxembourg: Outlining the History to Reflect on the Heritage

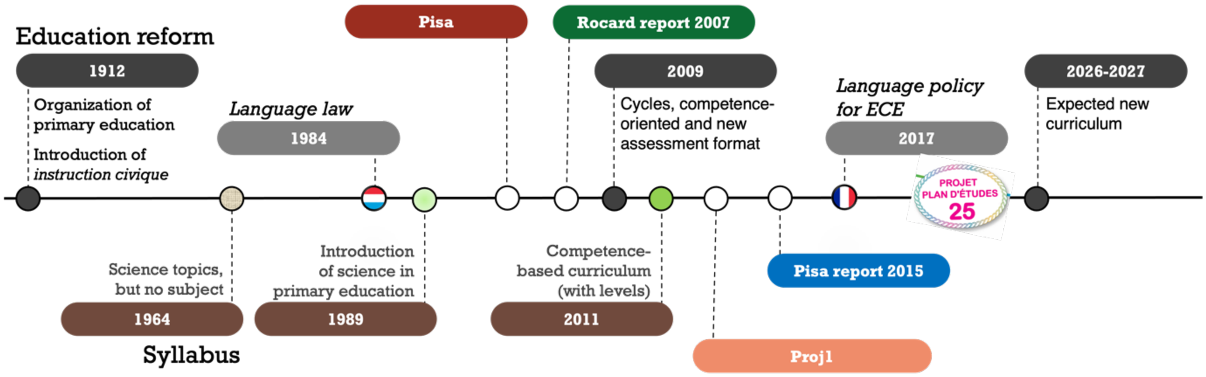
This contribution addressed the symposium general aim by exploring the emergence of primary science education research in the context of Luxembourg. This country in Europe hosts a highly diverse population. Its education system reflects this diversity as a high percentage of students speaking a home language other than the languages of instruction. Considering that language takes up a good part of the instruction hours, this scenario raises issues of equity and access to the different educational paths, such as science instruction, and the need to reflect on the past actions (especially to plan the future). The case study addresses two questions: (a) How are the science education policies articulated within Luxembourg's normative frameworks legislating primary education and what are the reflection/perception of stakeholders? and (b) What has been published regarding science education in Luxembourg? By systematically exploring these inquiries, this case study seeks to contribute valuable insights into the field of history of science education and history of science education research.

The Place Of Primary Science Instruction In Luxembourg

To present the place of science instruction in primary education an analysis of normative acts was undertaken through document analysis (Asdal & Reinertsen, 2022) to explore the Luxembourg context and outline the history of primary education and primary science curriculum. Additionally, to highlight stakeholders' voices from a policy research project within science education, the study examines interviews from SciPol by using thematic analysis. It was possible to map a timeline for the evolution of normatives that frame primary education in the national context

(Figure 1).

Figure 1. Timeline of educational legislation in Luxembourg



In general terms, the interviews discuss educational reforms since 1989, focusing on introducing new materials and teaching methods in sciences amid societal changes, particularly ecological movements. The discussion deals with the challenges and changes in school teaching, specifically around *Éveil aux Sciences* (Discovery of Sciences). It also looks at social motivations, teaching methods, the integration of technical subjects, and the need for interdisciplinary work. Challenges included insufficient teacher training and resistance to curriculum changes, yet a shift towards multidisciplinary approaches is noted. The analysis shows that teachers were dependent on materials and that new approaches were often met with resistance.

Table 1. Results retrieved and abstract screened

#	Author	Journal	Year
1	Siry & Lang	Journal of Science Teacher Education	2010
2	Siry & Lara	Cultural Studies of Science Education	2012
3	Kirch & Siry	Research in Science Education	2012
4	Siry & Brendel	Cultural Studies of Science Education	2016
5	Andersen	Environmental Education Research	2018
6	Gómez Fernández & Siry	International Journal of Science Education	2018
7	Andersen	Journal of Research in Science Teaching	2020
8	Siry & Wilmes	Cultural Studies of Science Education	2020
9	Siry & Gorges	International Journal of Science Education	2020
10	Siry	Asia-Pacific Science Education	2021
11	Wilmes & Siry	Research in Science & Technological Education	2024
12	Siry, Wilmes & Sportelli	Journal of Research in Science Teaching	2025

The Field Of Primary Science Education Research In Luxembourg

Historical research in Luxembourg has centred its focus on the history of the industry and paths connected to it, of the migration fluxes and of topics related to the wars (WWI and WWII). When it comes to the history of education centred in schooling, and more specifically to primary education, only 28 results are found within the national repository. A brief scanning of the resulting abstract leads to only two that considers the topic of "science education". This context reinforces the emergent need to conduct historical research in Luxembourg, taking into account the place of science in primary education.

Considering that historical research in the field of science education in Luxembourg is scarce, an exploratory mapping of the existing published research was done to situate the domain of science education research within the context of primary education. The search was focused on EBSCO*host* databases, using the following search strings ("science education" OR "science teaching" OR "science instruction" OR "science learning") AND ("primary education" OR "primary school" OR "elementary education" OR "elementary school") AND "Luxembourg". The results retrieved consist of 35 publications since 1977. Abstract screening allowed the focus to 12 publications, leading to a mapping of researchers and topics spanning from 2010 and 2025 (Table 1).

This exploratory mapping contributed to a better understanding of the research related to primary science education in Luxembourg and there seems to be a desideratum for historical research using broaden means for mapping/review, especially considering that research is arranged around one research team, led by Christina Siry, one of our co-authors.

Discussion: The Urgent Need to Historicise the Field of Didactics of Science

According to the authors' perspectives in this symposium, the history of didactics of science/science education should (almost necessarily) involve the following issues and themes: (a) Constructing a timeline, with recognisable "milestones"; (b) Proposing some "periods" with the aid of external factors (i.e., internal history of the field against the backdrop of social and political history); (c) Producing a narrative, with the inclusion of a "foundational myth" (ambitious national plans, large-scale programmes of reform, first PhD theses, seminal meetings, etc.); (d) Examining in depth its theories (and their "inspiring" authors); (e) Diachronically analysing the *problems* of research; (f) Studying the evolution of the literature and of its "vehicles" (conferences, journals, dissertations, etc.); (g) Identifying the institutions, groups and individuals who did research in the past, and the policies that facilitated and supported this; (h) Establishing links with the history of science education as a practice (paying special attention to its reforms and innovations)… and consequently with the history of science education as policy making; (i) Delving into the (long) history, modalities and institutions of science teacher education; (j) Recognizing the discipline's "disciples", and how they were enculturated; (k) Taking on board of the historization the actors, authors, stakeholders and audiences of the discipline; and (l) Telling it to the newcomers in the disciplines (junior researchers and teachers).

The *commonalities* of the four symposium contributions dealing with the emergence of the didactics of science/science education research field in the cases from France, Catalonia-Spain, and Luxembourg were the following: (a) Decisions on the methods that would be used to dig in the past and to narrate; (b) Strong theoretical positionings; (c) A conviction that the authors are doing empirical and argumentative research; (d) The need to pay homage to great figures; (e) Conscience of the limitations of the histories constructed so far; and (f) To some extent, an implicit assumption that didactics is a European creation.

Few *divergences* appeared between the different cases; these can become "challenges" for future historical research. One deals with the different conceptualisations of the prehistory and of the "zero of coordinates" of our field. Another divergence is related to the very different decisions on the sociopolitical events that would be selected to historicize the field. A third divergence points at the inhomogeneous identification of the audiences demanding didactical knowledge. Finally, it would be urgent to connect the emergence of the field with other experiences conducted in other geographical locations, such as Latin America, a region with strong pedagogical tradition and marked European influence in research styles and themes.

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Understanding Of Nature Of Scientific Inquiry (NOSI) In The Early Elementary School Years: Focusing On The Relationship To National Curriculum Standards

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The results of the Views About Scientific Inquiry-Elementary (VASI-E) survey conducted on third-grade elementary school students demonstrate that the distinction between scientific investigation methods, such as "observation" and "experimentation", is unclear among Japanese students in the lower grades. One of the reasons may be that science education in the early elementary school years in Japan is conducted in the context of integrated learning, and the scientific method is not explicitly presented in this context. Therefore, this study focuses on the early elementary school years and introduces a novel analytical perspective by extracting items related to the nature of scientific inquiry (NOSI) from Japan's National Curriculum Standards to examine approaches for assessing students' understanding of NOSI within the context of integrated learning. In addition, the results of the VASI-E survey were reanalysed using the proposed analytical perspective. As a result of the review of the National Curriculum Standards, it was found that the students should be aware of the characteristics and intrinsic value of nature, and the relationship and connection among them, through activities such as seeing, comparing, trying, forecasting, and devising, to realize their ideas and wishes. It was also noted that the process involves a variety of thoughts, judgments, and expressions. Although not explicitly stated in terms of "experimentation," it indicated the concept of including them. Therefore, we reanalysed the VASI-E survey results using two new analytical perspectives: "perform activities to realize ideas and wishes" and "recognize that various activities, thoughts, judgments, and expressions exist in the process of realizing ideas and wishes".

Keywords: NOSI, VASI-E, integrated learning

Background And Purpose Of The Study

This study investigates the assessment of students' understanding of scientific inquiry (SI) in early elementary school. In 2021, the researchers conducted a survey on third-grade Japanese students using the Views About Scientific Inquiry-Elementary (VASI-E) questionnaire and found low levels of understanding of the SI aspect of "there is no single set and sequence of steps followed in all scientific investigations." This finding was consistent with those of an international survey conducted on third- and fourth grade students from 35 countries and regions (Lederman et al., 2023). One of the factors may be that although the importance of IS has been emphasized at the national level, it is not properly addressed in textbooks and classes (Dogan, 2021; Lederman et al., 2023). In the National Curriculum Standards (NCS) of Japan, science education in early elementary school is implemented in the subject called "Living Environment Studies" (*Seikatsu-ka*), which emphases intergraded learning. At this stage, formal scientific terms such as, "experiment", are not explicitly introduced yet. Their formal science starts from the third grade for the students of 10 years old. This situation has made us think that we probably need a wider range of an evaluation method for those students who have undergone this kind of curriculum with the focus of integrated learning. Considering that, it should be meaningful to investigate the analytical perspective of the VASI-E to understand how we can accommodate an earlier stage of science education whose focus is intergraded learning. Therefore, this study investigates the assessment of students' understanding of SI in an integrated learning environment. Specifically, items related to Nature of Scientific Inquiry (NOSI) are extracted from the NCS to create a new analytical perspective, followed by an exploratory reanalysis of the VASI-E results.

Results Of The VASI-E Survey

The VASI-E survey was conducted in September 2021 on 62 third-grade students at an elementary school in Tokyo, Japan. The Japanese version of the VASI-E, its methodology, and evaluation procedures aligned with those later described by Lederman et al. (2023). The evaluation was administered by three researchers with prior training in coding with VASI-E. Prior to the survey, a research ethics review was conducted. Schools and parents were provided with a written explanation of the project, while students received oral explanations. Consent to participate was obtained based on their responses.

The VASI-E evaluates the following aspects of SI: (1) all investigations begin with a question, (2) scientists collect empirical data to answer their questions, (3) procedures are guided by the question asked, (4) data and prior knowledge are used to answer the questions, (5) there is no one single scientific method (Lederman et al., 2023). Table 1 presents the number of respondents and their results for each aspect, rated using a three-point scale (Informed, Mixed, and Naïve).

Table 1. Results of the VASI-E on third-grade students (*N* = 62)

Aspects of scientific inquiry	**Informed** Number of children (%)	**Mixed** Number of children (%)	**Naïve** Number of children (%)
(1) all investigations begin with a question	16 (25.8)	31 (50.0)	15 (24.2)
(2) scientists collect empirical data to answer their questions	24 (38.7)	21 (33.9)	17 (27.4)
(3) procedures are guided by the question asked	20 (32.3)	27 (43.5)	15 (24.2)
(4) data and prior knowledge are used to answer questions	12 (19.3)	35 (56.5)	15 (24.2)
(5) there is no one single scientific method	8 (12.9)	31 (50.0)	23 (37.1)

Note: A few of the data included in this table were reported by Suematsu et al. (2022).

Out of the 62 students, 37.1% were Naïve in Aspect (5). The question corresponding to the evaluation of this aspect was Question 1 (Q1), which narrated a story about a woman who travels around the world to look at birds and wonders about the relationship between the shape and size of a bird’s beak and the types of food it eats. The students were asked whether she was “like a scientist” and why (Q1a) and whether she was conducting an experiment and why (Q1b). Although the words "experiment” was presented in the question, it has not been introduced at this stage of Japanese education, as previously discussed. This may be the reason underlying students’ difficulty in responding to Q1.

Early Elementary Curricula In Japan

In Japanese elementary schools, the curricula for the first and second grades include subjects such as Japanese language; mathematics; *Seikatsu-ka*; music; art and handicraft; and physical education. Within this framework, science education is primarily conducted through *Seikatsu-ka* which focuses on students’ immediate environments such as school, home, and the local community. The curriculum emphasizes learning through concrete activities and experiences, thus reflecting integrated learning. This type of learning has been implemented during early elementary education, because it considers the developmental characteristics of children at these ages and provides continuity from integrated learning conducted through play in Early Childhood Education and Care. From the third grade onward, science education is formally introduced. For example, in the commentary on the NCS for Science, the term "experiment" is used in 157 instances, whereas it is not used at all in *Seikatsu-ka*. Meanwhile, the term "observation" appears 193 times in Science but only 7 times in *Seikatsu-ka*, which is distinctive. Differences in the presentation of SI methods, such as observation and experiment, in *Seikatsu-ka* and Science may become an important factor when assessing students' understanding of SI.

In *Seikatsu-ka*, students are expected to observe familiar nature to identify their differences and characteristics, increase their awareness of natural phenomena and seasonal changes, and develop an attitude of incorporating nature to enrich their experiences (Ministry of Education, Culture, Sports, Science and Technology (MEXT), 2018). In this context, observing familiar nature pertains to taking an interest in nearby natural surroundings, engaging directly with nature, and paying attention to it. Specifically, the following content is envisioned:

> Students develop an interest in nature by going outdoors, blowing dandelion fluff into the air, or following ant trails to find their nests. They repeatedly engage with nature using their senses—noticing the scent of dandelion flowers, the softness of the fluff, or intently watching the ants' movements. This allows them to fully experience nature's wonders through seeing, hearing, touching, tasting, and smelling. Through repeated encounters with nature, students begin to pay attention to the structure, color, and shape of dandelion flowers and fluff, as well as how ants carry food. In this way, they observe intently and become absorbed, guided by their own ideas and wishes. (MEXT, 2018; translation by the author)

Observation in *Seikatsu-ka* emphasizes the need for students to repeatedly engage with nature using their senses, guided by their own ideas and wishes, and, thereby, discover mechanisms inherent to nature. Furthermore, identifying differences and characteristics refers to the following:

> To discover differences and characteristics, it is important to have enough experience of direct contact and repeated interaction. It is also important to think by comparing natural phenomena and aspects of daily life, or by grouping them. For example, on a winter morning, they might find ice or frost crystals, feel the coldness of the ice, or enjoy the crunchy sound when stepping on frost crystals. If such play becomes a daily morning pleasure, they start searching for ice and frost crystals, discover they form in the same spots, and begin looking for similar locations. Visiting a park in autumn to collect and play with acorns. Once they gather many, they may sort them by size, shape, or color, or arrange them in patterns. Through such activities, students develop the ability to identify differences and characteristics in the nature around them. (MEXT, 2018; translation by the author)

In *Seikatsu-ka*, students are encouraged to consciously become aware of differences and characteristics. To develop this awareness, experiences such as sorting and arranging are emphasized. Additionally, in relation to the scientific method, the goal is to "create play and the tools for play through activities like utilizing nearby nature or using familiar objects, discovering their fun and wonders of nature, and working together to create play while enjoying it" (MEXT, 2018; translation by the author). For example, this aspect may involve discovering relationships between light and shadow through shadow-stepping games or creating moving toys. For example, children may wish to "make a car that runs fast" and engage in play through trial and error to achieve this goal.

Methods

Creating The New Analytical Perspective

Items related to the NOSI were extracted from descriptions of the "Objectives of *Seikatsu-ka*" in the NCS Commentary: *Seikatsu-ka* Edition (MEXT, 2018). In detail, using the keywords "question," "scientific method," "explanation," and "conclusion," which are included in the five SI aspects, the researchers further extracted descriptions related to these keywords. A new analytical perspective was then created by matching extracted contents with the VASI-E assessment.

Exploratory Reanalysis Of The Results Of The VASI-E Survey

The results of the VASI-E survey conducted in 2021 were reanalysed using the new analytical perspective. The analysis focused on Q1, which corresponded to the SI aspect that obtained the highest percentage of Naïve responses: "No single scientific method exists."

Results and Discussion

Table 2 presents the extracted NOSI descriptions and related keywords. The *Seikatsu-ka* curriculum does not use explicit expressions such as question and conclusion to represent aspects of NOSI. Instead, it uses subjective, ambiguous expressions to denote learning from life situations, through experience, and in an integrative manner, which are the primary characteristics of *Seikatsu-ka*. Nevertheless, its contents encompassed aspects of NOSI and were designed to connect to more generalized learning of science while teaching concepts appropriate for younger children.

Table 2. Descriptions related to the NOSI

Extracted descriptions (*translated by the author*)	**Key Words**
"Be aware of the unique characteristics and intrinsic value of nature, and, the relationships and connections among them." *(MEXT, 2018, p.12)*	Explanation
"Students will think analytically about themselves and their lives through learning activities such as seeing, comparing, and likening. They also think creatively through learning activities such as trying, forecasting, and devising." *(MEXT, 2018, p.15)*	Scientific method
"Think about 'what to do' and 'how to do it' to realize their ideas and wishes, and then actually do it, moving on to the next activity. In this process, various thoughts, judgments, and expressions exist." *(MEXT, 2018, p.14)*	Question, Scientific method
"When expressing, children think about the contents and methods of expression based on their awareness of the other person and the purpose." *(MEXT, 2018, p.15)*	Conclusion, Question
"The result of their expression may cause them to reconsider, or new ideas or wishes may arise, and they may return to the previous stage or move on to the next stage." *(MEXT, 2018, p.15)*	Conclusion, Question,

Note: Underlined text is considered relevant to the keywords.

Using the extracted statements as a guide, the researchers developed new analytical perspectives (Table 3), contrasting them with the five aspects of SI. Table 4 presents the results of the reanalysis of Q1 of the VASI-E survey using the proposed analytical perspective based on integrative learning (Table 3). Table 5 presents a comparison of scoring obtained using the new analytical perspectives with VASI-E scoring.

Table 3. Analytical perspectives on NOSI in the early elementary school years

SI aspects	Analytical perspectives	Related VASI-E questions
(1) All investigations begin with a question.	Activities are conducted to realize ideas and wishes.	1a, 4a, 4b
(2) Scientists collect empirical data to answer their questions.	Through activities such as seeing, comparing, likening, trying, forecasting, and devising, the students will gain a variety of ideas and awareness.	2a, 2b
(3) Procedures are guided by the question asked.	Activities ("what to do" and "how to do") are considered for the realization of ideas and wishes.	3, 4a
(4) Data and prior knowledge are used to answer questions.	Levels of awareness among students are enhanced by confirming similarities, differences, relationships, and connections between ideas. The results will lead to rethinking and the formulation of new questions.	2a, 2b
(5) There is no one single scientific method.	The participants gain awareness that various thoughts and activities are involved in the process of realizing their ideas and wishes.	1a, 1b

Note: For related VASI-E questions, see Lederman et al. (2023).

Table 4. Reanalysis of VASI-E results for third-grade students (N = 62)

Aspects of SI		**Informed** Number of children (%)	**Mixed** Number of children (%)	**Naïve** Number of children (%)
(5) There is no one single scientific method.	VASI-E Scoring	8 (12.9)	31 (50.0)	23 (37.1)
	New analytical perspectives	23 (37.1)	29 (46.8)	10 (16.1)

According to the VASI-E scoring, 12.9% of the students were classified as Informed, but this proportion increased to 37.1% after the reanalysis, while the proportion of students categorized as Naive decreased from 37.1% to 16.1%. Considering these changes in detail: 10 students' classification transitioned from Naive to Mixed, 11 students changed from Mixed to Informed, and 4 students changed from Naive to Informed. In Example 3, in which students were classified as Informed only in the new analysis scoring, the students described experimentation in terms of trying. In addition, in Example 2, the results confirmed that students are attempting to change their ideas and wishes into more scientific concepts.

Conclusion

Responses classified as Informed using both scoring systems were more scientifically sophisticated; thus, expecting such responses in science education after the third grade is important. Alternatively, responses categorized as Informed only using the new analytical perspective, which is grounded in integrated learning, fell on the borderline between Scientific and Naive. These qualitative differences between scientifically sophisticated and borderline responses emphasize developmental progression as students transition from integrated learning to focused scientific education after third grade.

Table 5. Comparison of results between the new analytical perspectives and VASI-E

		New analytical perspectives		
		Informed	Mixed	Naïve
VASI-E Scoring	Informed	7	1	0
	Mixed	11	18	2
	Naïve	4	10	8

Ex. (1) Both were Informed.
1a: (Informed) *I thought she was like a scientist when she tried to examine birds' beaks and food.*
1b: (Informed) *I think she is conducting an experiment because she has set out to solve a problem: "Is there any relationship between the size and shape of birds' beaks and the type of food they eat?".*

Ex. (2) Only the new analysis perspective was Informed (Mixed → Informed).
1a: (Informed) *Because normally, I would only think, "That's a mystery," because she wanted to find out.*
1b: (Informed) *Because she would wonder, "Why do their beaks look different?" and because she was paying attention to what they were eating.*

Ex. (3) Only the new analysis perspective was Informed (Naive → Informed).
1a: (Mixed) *Because she observes a lot of different birds.*
1b: (Informed) *Experiments are about trying things out.*

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