

Part 8 / Strand 8

Scientific Literacy And Socio-scientific Issues

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Part 8 / Strand 8 Scientific Literacy And Socio-scientific Issues

Teaching and learning about scientific literacy, socio-scientific issues and citizenship education. Topics in the strand include understanding the social aspects of science, critical media/literacy reasoning, decision making and debates on socio-scientific issues (SSI), public engagement and participation in science and understanding the relevance of science. The aforementioned topics can focus either on teachers or students.

Sub-themes:

- 1) Teaching and Learning about Scientific Literacy
- 2) Engaging Students in Socio-scientific Issues (SSI)
- 3) Critical Media Literacy in Science Education
- 4) Public Engagement and Participation in Science

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Strand 8: Scientific Literacy And Socio-scientific Issues

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The chapter "*Scientific Literacy and Socio-scientific Issues*" brings together contributions that tackle a significant challenge in today's science education: preparing learners and teachers to engage critically, responsibly, and thoughtfully with science in a complex and unpredictable world. Socio-scientific issues (SSI) have received more attention over the past twenty years because many problems facing modern societies—like climate change, loss of biodiversity, artificial intelligence, genetic technologies, food security, public health crises, and sustainability transitions—cannot be understood or solved with scientific knowledge alone (Sadler, 2004; Zeidler et al., 2005; Levinson, 2018). These issues involve uncertainty, different perspectives, competing values, and the necessity of making choices despite incomplete information. Citizens need to engage not only with scientific facts but also with ethical, cultural, economic, and political factors. The growing importance of SSI is especially clear in what is often called a post-truth era. Here, scientific information competes with misinformation, disinformation, ideological narratives, and content shaped by algorithms circulating in digital media (Lewandowsky et al., 2017; Erduran, 2025). As a result, scientific literacy has become both more crucial and harder to achieve. Modern scientific literacy goes beyond knowing scientific concepts and procedures. It includes the ability to evaluate evidence, assess the credibility of sources, recognize uncertainty, understand how scientific knowledge is created and shared, and engage meaningfully in public discussions and decision-making processes (OECD, 2019; National Academies of Sciences, Engineering, and Medicine, 2016). In this context, socio-scientific issues have been increasingly recognised as a powerful educational approach for preparing learners for responsible citizenship, as they engage students in considering the relevance of science in societal decision-making and encourage them to evaluate scientific, ethical, political, and cultural dimensions of contemporary problems (Evagorou & Dillon, 2020).

Developing such capacities is not only a challenge for students but also for teachers, researchers, educational institutions, policymakers, and society as a whole. A major factor driving these changes is the fast rise of artificial intelligence. AI has entered everyday life, workplaces, education, research, and public discussions at an unmatched speed. Technologies like machine learning, recommender systems, generative AI, and large language models have changed how information is produced, shared, and consumed. While these advancements provide new chances for learning and scientific communication, they also raise significant questions about transparency, ethics, data privacy, bias, accountability, and the reliability of information (Long & Magerko, 2020; Ng et al., 2021). Therefore, learners today need not just digital skills but also a critical perspective on technology, helping them understand and assess the social effects of new technologies. From an education standpoint, these fast changes call for new skills and new forms of literacy. People increasingly need to make decisions on issues with uncertain, long-term, and hard-to-predict consequences. Students, teachers, researchers, policymakers, and communities often face questions without clear or universally accepted answers. Choices about climate action, biotechnology, public health measures, sustainability, or regulating AI often have to be made before all relevant evidence is available and without certainty about future outcomes. Thus,

preparing learners to handle this uncertainty is a key goal of science education (Funtowicz & Ravetz, 1993; Levinson et al., 2017).

In this context, the contributions in this chapter provide valuable insights into fostering scientific literacy and engagement with socio-scientific issues across various educational settings. A strong theme throughout the chapter is the connection between scientific literacy and the fast-changing digital world. Several studies examine how learners understand artificial intelligence, machine learning, social media, and science communication, highlighting both the opportunities and challenges these environments present for developing critical tech and media perspectives. Issues of misinformation, source evaluation, trust in science, and the responsible use of digital technologies emerge as key concerns for science education in the twenty-first century.

Another major focus is socio-scientific reasoning and argumentation. The contributions investigate how students and future teachers think through complex and controversial topics like sustainability, climate change, resource use, biotechnology, and emerging technologies. They explore the development of argumentation, critical thinking, moral reasoning, and decision-making. They show that meaningful engagement with socio-scientific issues requires learners to connect scientific knowledge with ethical, cultural, economic, and societal factors.

The chapter also emphasizes the essential role of teacher education. Several studies analyse how future teachers gain the knowledge and skills needed to promote SSI-based learning. They pay particular attention to culturally responsive teaching, sustainability reasoning, and designing learning environments that help students relate scientific knowledge to their own experiences and cultural backgrounds. These contributions acknowledge that teachers are not just sources of knowledge but also key guides who assist students in navigating uncertainty, evaluating competing claims, and engaging in informed and responsible decision-making.

Overall, the studies in this chapter show that scientific literacy today is closely linked to the ability to engage with socio-scientific issues. They stress the need for educational approaches that encourage critical inquiry, ethical thinking, evidence-based reasoning, and active participation in democratic societies. By doing this, the chapter supports ongoing efforts to rethink science education for a world marked by rapid technological change, global connections, and increasing uncertainty.

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Manipulation Of Illustrations And Graphs In Chemistry Education

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Challenges like manipulation and misinformation are of particular importance in the context of modern types of media due to the absence of classical gatekeeping mechanisms. Especially illustrations and graphs with a scientific background can be manipulated in various forms. Due to the influence manipulation strategies can potentially have on society, the promotion of competencies enabling individuals to detect manipulation is needed. Therefore, a teaching unit that deals with the analysis of illustrations and graphs in chemistry education and the detection of manipulation strategies used in media content was created. In the four lessons, the students became familiar with different strategies and aims of manipulators. The media content of the teaching unit is embedded in a chemical or scientific context, and the illustrations are adapted to the design of known social media platforms. The exploratory evaluation of the unit included open-ended questions and a Likert-type questionnaire. It was investigated to which extent the students can describe the manipulation strategies used in specific illustrations and graphs at the end of the unit. The results of the evaluation show that the students are able to describe manipulation strategies used in exemplary media content by utilizing vocabularies resembling the manipulation strategies learnt in class. However, the majority is not able to identify all the different strategies. Consequently, the teaching unit seems to be able to partly promote Scientific Media Literacy, but additional practice and the acquisition of a routine is needed.

Keywords: Case Studies, Classroom Practices, Scientific Literacy

Theoretical Background

Relevance

Due to the increasing digitalization and its challenges, the promotion of media literacy became relevant as an educational and macro-social intersectional issue in Germany (KMK, 2017) and worldwide (UNESCO, 2021). Therefore, it is being integrated into different subjects. Media literacy is also important for the everyday life of young people as they regularly get confronted with media content – that often has a scientific background – and also have to deal with digital media's challenges. However, regular interaction with such content does not always mean that the interaction is reflected by users, and challenges like manipulation and misinformation occur frequently in digital media (Barzilai & Chinn, 2020; Kammerl, 2014; Tulodziecki et al., 2021). But without a deepened reflection of the content, the influence of manipulation and misinformation grows. In particular, illustrations are the aim of manipulation, because pictures taken by a camera are often associated with higher evidence (Schicha, 2005; Stein et al., 2020). Misleading graphs play a major role in advertising in order to present the product in an appealing light (Danciu, 2014).

Manipulation Strategies

Connected to manipulation, media content can be rapidly altered through strategies such as the choice of colours or changes in context created by accompanying text (Danciu, 2014; Schicha, 2005). Graphs, which are frequently used in advertisements, are also susceptible to manipulation in various ways (Danciu, 2014), for example through colour choices or by adjusting the axis range (Schaffer, 2020; Walla, 2008). This shows that manipulating media content is not particularly

complicated, which is why it is an important issue that needs to be addressed in the context of increasing digitalization. Furthermore, the media is able to influence the public perception of different issues, for example by using manipulation strategies. With regard to chemistry, the consumption of manipulated content can evoke, for instance, aversions and fears (Rollini et al., 2022). This phenomenon of creating irrational fears towards chemistry and chemicals is known as chemophobia (Rollini et al., 2022). However, the opposite can also be achieved by using manipulation strategies that suggest seriousness and scientific credibility even in areas where these are absent (Höttecke & Allchin, 2020). Additionally, the media can change the perception of scientific debates (Lewandowsky et al., 2019). Taken together, these aspects complicate interaction with digital media, particularly social media, when individuals seek to engage deeply with content. Consequently, educational contexts must foster competencies that enable learners to address these challenges effectively.

Application To Education

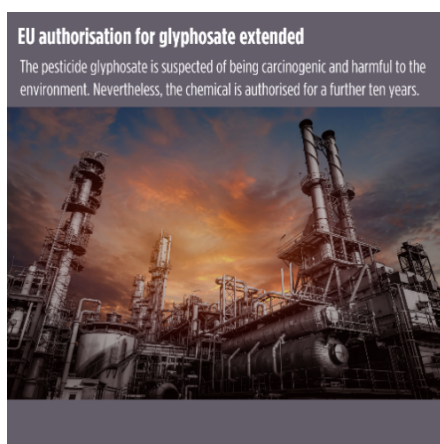
In order to overcome the challenges of digital media in a responsible manner, a reflected interaction with content is needed, especially when it comes to science-based information (Chang Rundgren & Rundgren, 2014). Illustrations and graphs with a scientific background are examples which can often be found in the digital media and can be manipulated in different ways, particularly on social media platforms due to the absence of traditional gatekeeping mechanisms (Höttecke & Allchin, 2020). In an educational context, a mainly preventive approach is needed, supporting students to deal with manipulated media content in the future (van der Linden, 2022). Teaching units dealing with topics like manipulation are important to promote students' critical interaction with digital media and the scientific information in it.

In the case of science-based media content, the concept of Scientific Media Literacy describes the skills and knowledge needed to deal with it (Chang Rundgren & Rundgren, 2014). The concept combines the fields of Scientific Literacy and Media Literacy and can be integrated and promoted in the science classroom (Chang Rundgren & Rundgren, 2014).

Development Of The Teaching Unit

Based on the described challenges, the aim of this exploratory study was to develop and evaluate a teaching unit of four school lessons on the topic of manipulation of illustrations and graphs in chemistry education and to (at least partly) promote Scientific Media Literacy. It has been investigated to which extent the students are able to describe the manipulation strategies used in specific illustrations and graphs at the end of the unit. The target group were German students in grades 9 to 11, and the focus of the lessons was on the analysis of different science- and chemistry-based illustrations and graphs. In addition, the students evaluated different media contents in different exercises and created their own manipulated illustrations to change their perspective. They became familiar with various manipulation strategies and how to detect them. The scientific backgrounds of the media content were chosen to be controversial. Topics like cosmetics, glyphosate, clean and natural beauty, nutritional supplements, plastics, and energy supply were part of the teaching unit. All the images were created using the software Canva based on a prior analysis of existing social media posts to allow a clear focus on the manipulation strategies and decrease distraction. An example of such manipulated media content can be seen in Figure 1.

Figure 1. Exemplary illustration of the teaching unit about glyphosate.



Detailed prior knowledge about the topics was not needed to answer the different tasks. For exercises which supposed a more comprehensive knowledge about the specific issue, information texts were created to support the students.

Methods

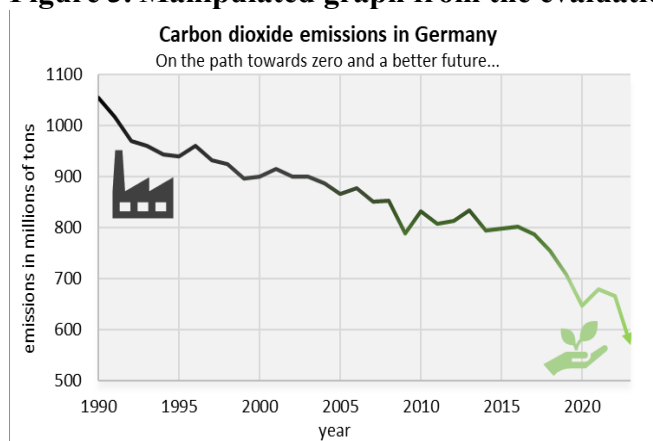
To investigate the impact of the unit on the students a mainly qualitative approach was used, which consisted of a participant observation and an evaluation sheet which combined open-ended and Likert-typed questions as well as two exercises in which the students had to describe the manipulation strategies used in two exemplary media contents (Figure 2, 3) and questions including feedback on the teaching unit. The unit was implemented and evaluated in a group of 53 students from grades 9 to 11. The participant observation was used to improve the identification of difficulties that occurred during the lessons, while the main part of the evaluation consisted of the evaluation sheet.

The media content used in the exercises of the evaluation sheet can be seen in Figures 2 and 3, each of them has been manipulated by applying several strategies. The students were not familiar with these specific examples and therefore had to apply the strategies they have learnt in their descriptions. Figure 2 has been manipulated by the choice of colours, added image elements such as plants and laboratory equipment, the proportions of the different parts of the figure, and the accompanying text (Schicha, 2005; Stein et al., 2020). Especially the percentage of visible moisture increase without context and information about the origin is misleading (Danciu, 2014). The manipulation strategies of Figure 3 consist of the choice of colours, unnecessary details such as the arrow at the end of the curve and the two symbols, the accompanying text, and the changed axis range (Schaffer, 2020; Schicha, 2005; Walla, 2008).

Figure 2. Manipulated illustration from the evaluation.



Figure 3. Manipulated graph from the evaluation (source of data: Umweltbundesamt, 2023).



The additional feedback on the teaching unit included aspects like the interest in the topic, the quality of the unit, and the self-assessment of the students' own learning gains. To obtain answers on these aspects, Likert-typed questions, open-ended questions, and a self-assessment of the individual learning gains on a scale from one to ten were used.

After the editing of the evaluation, the open-ended questions of the evaluation sheet were analysed using qualitative content analysis (Kuckartz & Rädiker, 2022) and for the Likert-typed questions we used descriptive statistics due to the exploratory nature of the study. Categories were formed based on the students' descriptions (Kuckartz & Rädiker, 2022) and afterwards compared with the manipulation strategies from the lessons described above. In addition, mean values and standard deviations of the Likert-items and the self-assessment of the individual learning gains were calculated.

Results

Description Of Manipulation Strategies

The results of the exercises show that most of the students are able to describe the manipulation strategies used in illustrations and graphs at the end of the teaching unit. Therefore, they are able to recognize manipulated media content. To describe the manipulation strategies, the students mainly used the vocabularies learnt in class. However, in most cases the students are not able to identify all the strategies from the two examples (Figure 2, 3).

Especially manipulation strategies like the choice of colours or the influence of the context, which has been changed by the text of the media content, are often detected by students. These strategies occur in both types of media and were therefore repeatedly addressed in the unit. When describing Figure 2, the majority of students refer to the text containing the percentage. The visual elements that establish a connection to nature and chemistry, such as the plants and laboratory equipment, were also often recognized. References to nature are mentioned by more than the half of participants.

It was discovered that the analysis of the graph seems to be more difficult for some students than the analysis of the illustration. The most frequently mentioned category is the choice of colours within the graph of Figure 3. The two symbols are also often described as manipulative. Manipulation strategies associated with mathematics, such as the changed axis range in Figure 3, were described less frequently and therefore seem to be more difficult for most of the students to detect. Here, the difficulty seems to be that the students have to learn how to read a graph at first (Schaffer, 2020). After that, they gain a basis to learn how to detect the manipulation of the graph

more in detail. To minimize the difficulties with graphs, general competencies for the interaction with them are needed in different subjects such as mathematics and the sciences.

The descriptions of manipulation strategies in illustrations and the results of year 11 are more comprehensive than in years 9 and 10. On average, older students describe more strategies in their descriptions, which goes in line with research findings on consumer socialization (John, 1999). Nevertheless, most students in all grades can identify at least one strategy, which means that they are aware that manipulation is present. In addition, it is noticeable that some students have begun to interpret the effects and intentions of the strategies. This was not expected in both tasks.

Feedback

Self-Assessment Of Learning Gains

In addition, the students rate their own learning gains as rather high than low, with an average of 6.43 out of 10. The average of year 11 is the highest with 6.76, and the average of year 9 the lowest with 6.06. The standard deviation is particularly high in the ninth grade, which shows that differences within the learning group exist. While two students even reported learning gains of 10, another student of the same class reported a gain of 1. The result of the self-assessed learning gains as a whole could relate to the self-assessment of a higher previous knowledge and the fact that the teaching unit mainly promotes skills and less factual knowledge. In the ninth grade, general differences in performance within the learning group may also have been an influencing factor.

Open-Ended Questions

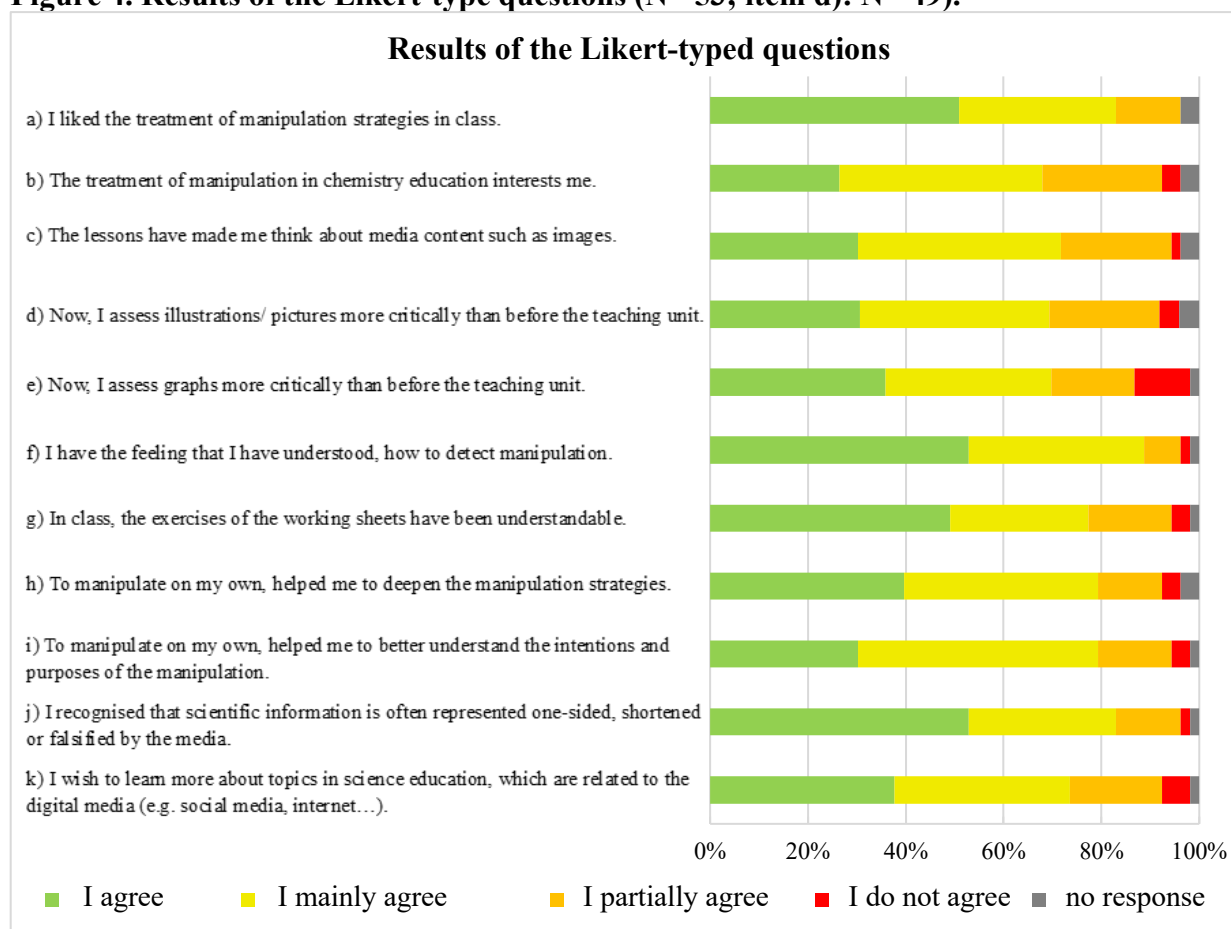
Overall, the feedback concerning the interest in the topic, the learning gains and the whole unit is quite positive. Many positive aspects like the creation of an own manipulated illustration and the relevance of the topic are mentioned in the open-ended questions. In relation to the relevance of the topic, one of the students highlighted that he has never learnt to detect manipulation strategies before. This confirms the necessity for promoting comparable skills in education. The differences between the grade levels show that especially younger students need additional support for the tasks in class.

The general difficulty of the topic was also mentioned by some students, while others assessed their previous knowledge as high. The high level of previous knowledge could often not be proved by the students' performances in the exercises of the evaluation. This may be connected to the difficulties of self-assessment (Riese & Reinhold, 2014). It is also possible that some students underestimate the topic due to its close connection to everyday life, while others are more aware of the challenges associated with manipulation.

Likert-Typed Questions

Overall, the results of the Likert-type questions are positive. The results (Figure 4) show, among other aspects, that most students had the feeling to understand how to detect manipulation which is a sign of success of the unit. The majority also seem to have benefits from manipulating media content by themselves. There were major differences between the grades in terms of their perception of the comprehensibility of the tasks in class. In the eleventh grade, all students agreed or mainly agreed that the tasks were understandable. This may be because some of the younger students need additional support with the tasks. Furthermore, nobody fully disagreed that they liked the topic of manipulation strategies in class. It seems to be a motivating topic for education.

Since four students were ill during the lessons on the illustrations but took part in the evaluation, item d) was not taken into account for them (Figure 4).

Figure 4. Results of the Likert-type questions (N= 53; item d): N= 49).

Conclusions

The results demonstrate that the teaching unit seems to be able to contribute to the promotion of Scientific Media Literacy, especially concerning the media analysis (Chang Rundgren & Rundgren, 2014). The promotion is mainly designed to be preventive in order to prepare the students to deal with manipulated illustrations and graphs in the future (van der Linden, 2022). The fact that the students mainly feel secure when it comes to the detection of manipulation strategies (shown in Figure 4) is a sign that the teaching unit is able to support them.

However, the unit is not able to realize the promotion of Scientific Media Literacy on its own. Support by further units, an expansion to the other dimensions of the concept, and more practice is needed. The domain of knowledge is also integrated in the teaching unit through the scientific background of the media content and the creation of manipulated illustrations (Chang Rundgren & Rundgren, 2014), but this specific domain should also be further promoted. In addition, it would be interesting to measure students' learning process in connection with teaching units in the area of Scientific Media Literacy at different points in time following the unit. That would also reveal more about how long the effects of interventions last.

All in all, the topic of manipulation seems to be relevant for the students' daily lives, which can be supported by their answers in the evaluation. Science education plays an important role in promoting the competencies needed to address challenges related to the distortion of scientific information in the media.

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How Do Greek Students And Teachers Perceive Climate Change?

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Probing people's perceptions about climate change is crucial for the design of communicational and educational practices that will motivate environmentally responsible behaviour. In this study, we explored Greek students' and teachers' perceptions about climate change. The participants (N = 166) perceive climate change to be real and primarily human caused and as a certain and present risk for them and their country. Perceptions of scientific uncertainty vary, with secondary school educators and students expressing higher levels compared to the ones of educators and students in tertiary education. Moreover, the impacts of climate change elicit moderate levels of concern among participants. A correlation was found between participants' perceptions of psychological temporal distance from climate change and their educational group (secondary/tertiary education teacher or student). Finally, participants mainly trust scientists, environmental organizations and teachers as sources of information regarding climate change. The findings contribute to the understanding of how the stakeholders of the Greek educational community perceive climate change, which should guide the design of more targeted and effective educational strategies.

Keywords: Assessment, Public Understanding of Science, Quantitative Research

Introduction

Climate change presents a significant and urgent threat to humanity (Mbah, 2024). Public perception of climate change plays a vital role for the development of effective solutions (Weber, 2010). This is because successful climate policies necessitate public support, which relies on well-informed citizens advocating for meaningful action (Pidgeon & Fischhoff, 2011).

Many studies have examined people's climate change perceptions of various types and by using diverse measurements. The current study concerns six distinguishable types of climate change perceptions, namely (a) the existence and causes of climate change, (b) concerns about the effect of climate change, (c) the personal risk of the effects of climate change, (d) the psychological temporal distance (whether people perceive the effects of climate change as occurring soon or in the distant future), (e) the perceived scientific uncertainty, and (f) the trust of information sources.

The first two types of perceptions fit with arguments of climate change sceptics, which first focus on denial of the reality of climate change, then move towards attributing it to natural causes rather than human activity and downplaying the extent to which climate change would bring about negative consequences (van Valkengoed et al., 2021).

The psychological temporal distance and uncertainty of the effects of climate change have been suggested as dimensions of people's climate change perceptions (Spence et al., 2012). Uncertainty refers to complex, encompassing scientific disagreement and the inherent unpredictability of climate systems and it is often confused with scepticism (Spence et al., 2012; Weber, 2010). Significant scientific uncertainty surrounds the potential impacts of climate change due to the immense complexity of climate systems and their interactions with human and biological systems. Our understanding of these intricate systems remains incomplete and there may be large considerable scientific disagreement and uncertainty around the potential impacts

of climate change. On the other hand, scientific disagreement and uncertainty are the sceptics' justification for the denial of climate change. Therefore, it is crucial to be precise when discussing scepticism and uncertainty related to climate change. Media often misrepresents scientific controversies and tends to focus on minimizing consensus, thus promoting the creation of confusion among the public (Pidgeon & Fischhoff, 2011). This misinformation poses a challenge for scientists and educators. People generally prefer certainty, and communicating uncertainty can hinder climate action (Weber, 2010). However, the interplay between uncertainty and other climate change perceptions remains understudied (Spence et al., 2012).

Climate change perceptions differ significantly between scientists and the public (Mbah, 2024; Myers et al., 2021). This disparity arises partly from the abstract nature of climate change, making it difficult for individuals to accurately perceive based on personal experience (Weber, 2010). Therefore, scientists, media, and educators play crucial roles in detecting and communicating climate change information. Moreover, people's trust and attention are key factors in how they perceive climate change information and individuals are more likely to pay attention to and incorporate information from trusted sources (Weber, 2010). The way climate change information is communicated and amplified by scientists, media, cultural groups, and other sources significantly shapes individuals' perceptions and actions to this critical issue (Weber, 2010).

Most research on climate change perceptions has focused on adults, while the need for effective educational strategies necessitates a holistic exploration of both student and teacher perceptions. Moreover, in Greece there has been so far no systematic research aiming at measuring the climate change perceptions of the educational community. Taking into consideration the discussion above, the present study addresses the following research question:

What are the climate change perceptions among Greek students and teachers in secondary and tertiary education?

Method

Participants

The participants are upper secondary education students ($n=28$, age 16–17 years) and teachers ($n=34$, age >25 years), as well as undergraduate students ($n=89$ age 18–22 years) and tertiary education teachers ($n=15$, age >35 years). The survey was conducted online via Google Forms.

Instrument

The instrument consists of 3 parts. The first part is composed of 25 items related to perceptions about climate change assessed by a Likert-type scale ranging from “strongly disagree” (0) to “strongly agree” (10). Moving from “strongly disagree” to “strongly agree,” positive items were scored from 0 to 10, respectively, while negative items were scored in the reverse order. In the instrument the terms climate change and global warming are used interchangeably, since they are usually treated as equivalent in public discourse.

An exploratory factor analysis (EFA) followed by confirmatory factor analysis (CFA) of our data resulted in four scales corresponding: (a) Personal Risk Perceptions (5 items, Cronbach's Alpha=0.819), (b) Global Warming Beliefs (8 items, Cronbach's Alpha=0.812), (c) Scientific Uncertainty (4 items, Cronbach's Alpha=0.703), and (d) Climate Change Concerns (3 items, Cronbach's Alpha= 0.821). The values of Cronbach's Alpha exceed 0.7 for all four scales, thus indicating satisfactory internal consistency (Field, 2013). Detailed results of EFA and CFA accompanied by the reliability and validity evidence of the data gathered are reported in a submitted manuscript.

The second part consists of ten items related to trust in ten different information sources (family members, friends, scientists, the government, energy suppliers, environmental organizations, media, social media, internet, teachers). Participants' responses to each item were assessed using a Likert-type scale ranging from "no trust" (0) to "absolute trust" (10).

Finally, the third part is an item related to the psychological temporal distance. Participants were asked to answer question "When do you think global warming will start to harm people in Greece?" choosing among (a) they are being harmed right now, (b) in 10 years, (c) in 25 years, (d) in 50 years, (e) in 100 years, (f) beyond the next 100 years, and (g) never. All the items were developed based on previous research (Özdem et al., 2014; Spence et al., 2012).

Results

Perceptions About Climate Change

The descriptive statistics (mean value, standard deviations) regarding the four scales derived from the exploratory factor analysis are shown in Table 1. Data is reported for the whole sample as well as for each of the four distinct demographic groups which comprise it.

Table 1 Descriptive statistics of four scales corresponding to perceptions about climate change

		Total (N=166)	Secondary students (N=28)	Secondary teachers (N=34)	Undergraduate students (N=89)	Tertiary teachers (N=15)
Scale		Statistics				
Personal risk perceptions	Mean	8.12	7.47	8.42	8.16	8.33
	SD	1.44	1.76	1.36	1.29	1.62
Global Warming Beliefs	Mean	8.51	8.17	8.36	8.64	8.75
	SD	1.20	1.21	1.45	1.10	1.10
Scientific Uncertainty	Mean	5.91	5.71	5.68	6.01	6.18
	SD	1.95	1.54	2.25	2.02	1.56
Climate Change Concerns	Mean	6.65	6.87	6.82	6.43	7.13
	SD	2.29	2.28	2.54	2.18	2.39

^aAll scale values range between 0 and 10

^bHigher scores correspond to lower uncertainty

The personal risk perceptions scale reveals the subjective nature of how people perceive the risks associated with climate change. For instance, the item "Global warming will harm me personally" directly reflects an individual's perception of personal risk while the item "Global warming will harm people in Greece" reflects the participant's risk perception related to locality.

In this study, Greek students' and teachers' personal risk perceptions of climate change have mean values ranging from 7.47 to 8.42 indicating their high awareness about the effects of climate change in their country and lives.

The global warming beliefs scale is comprised of 8 items that reflect different beliefs about: (a) the causes of global warming, (b) the personal thoughts and scientific consensus about whether global warming is happening, (c) the severity of the issue, and (d) the potential consequences of global warming. As shown in Table 1, all participants responses' mean values fall in the range between 8.17 and 8.75, thus indicating that they think global warming is happening and that it is mostly anthropogenic. They do not consider the seriousness of climate change as exaggerated as they perceive that it will harm the living organisms and the future generations.

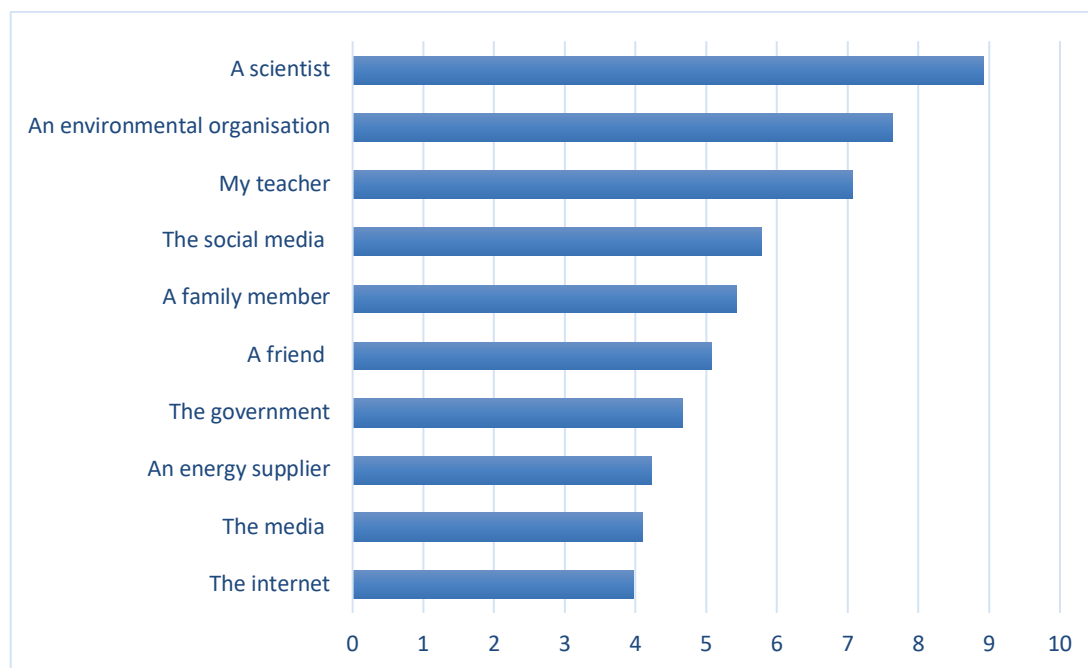
The scientific uncertainty scale consists of 4 items, which focus on the perceived or actual lack of scientific consensus, the uncertainties and the debate regarding climate change. The participants' responses reveal varying levels of perceived scientific uncertainty. Secondary teachers and students exhibited higher levels, while tertiary teachers and undergraduate students demonstrated lower levels. An analysis of participants responses to each item reveals that all of them concurred that “most scientists agree about climate change impacts” and that “there is not too much conflicting evidence about climate change.” Conversely, tertiary teachers acknowledged that “there is a disagreement among scientists about whether global warming is happening” but “it is certain what the effects of climate change will be” while the other groups of participants held opposing views.

The 3 items that constitute the climate change concerns scale reflect the emotional anxiety experienced by individuals due to concerns about the consequences of climate change. The results indicate that climate change impacts elicit moderate levels of worry among Greek secondary and tertiary students and teachers, with mean scores ranging between 6.43 and 7.13.

Trust In Information Sources

Scientists (Mean=8.92, SD=1.16), followed by environmental organizations (Mean=7.63, SD=2.00) and teachers (Mean=7.63, SD=2.00) stand higher regarding the participants' trust as sources of climate change information. On the other hand, participants trust much less the internet (Mean=3.97, SD=2.40), media (Mean=4.10, SD=2.53), energy suppliers (Mean=4.22, SD=2.73), and the government (Mean=4.67, SD=2.70), as Figure 1 represents.

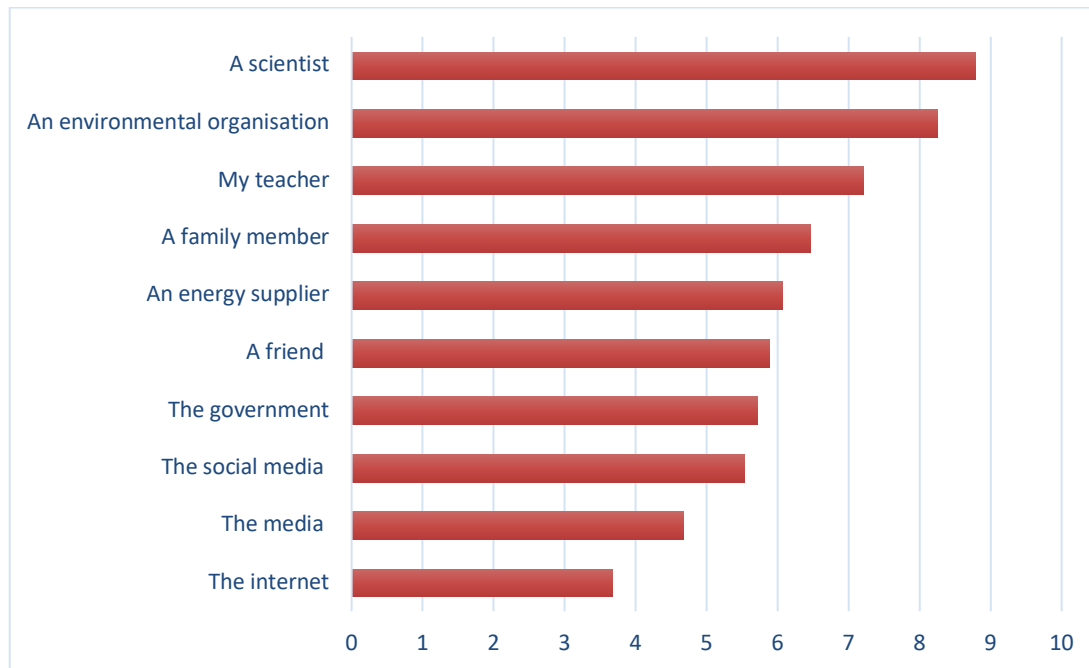
Figure 1. Mean responses on trusted sources regarding climate change



An interesting finding is that upper secondary students also trust more the scientists (Mean 8.79, SD 1.03), the environmental organizations (Mean 8.25, SD 1.38) and their teachers (Mean 7.21, SD 1.95) rather than the social media (Mean 5.54, SD 1.84) as shown in figure 2. Although, research has been shown that secondary students usually show a high level of trust in social media platforms (Haile, 2024), the upper secondary students of this study are not trusting information found on social media as much. Lower secondary Turkish students also identified scientists as a trustable source of information (Özdem et al., 2014). Zilz and Höttecke (2025) proposed that trust strategies, sources or representatives are evaluated based on the three indicators of trustworthiness: expertise, integrity, and benevolence. These indicators are indeed largely served by scientists, teachers, and environmental organizations. The academic profile, the specialized

knowledge and the transparency and effort to convey current scientific knowledge as accurately as possible without any conflicting interests, are the characteristics of these sources which contribute to trustworthiness.

Figure 2. Upper secondary students' mean responses on trusted sources regarding climate change.



Psychological Temporal Distance

With respect to the perceived psychological temporal distance, about three quarters of undergraduate students (73.0%), as well as secondary (79.4%), and tertiary teachers (73.3%), but much less upper secondary students (35.7%) think people in Greece are being harmed by global warming right now. Specifically, only 10 out of 28 upper secondary students reported that they are being harmed by global warming right now, while 5 of them reported that they will be harmed in the distant future either in 100 year (one student) or beyond the 100 years (three students), and one responded “never”.

The results of a chi-square test (bootstrap with number of samples 1000 and confidence interval level 95.0%) suggest that there is a correlation between perceptions of psychological temporal distance for climate change and the four educational groups ($\chi^2=25929.785$, $df=18$, $p<.001$).

Conclusions

Knowledge of the perceptions regarding climate change can help the design of effective strategies to promote environmentally responsible behaviour among the public. Participant responses strongly suggest a consensus that global warming is real and primarily human caused. They do not view climate change as overstated due to concerns about its impact on living organisms and future generations. Their scientific uncertainty perceptions vary with secondary teachers and students expressing higher levels of uncertainty relative to tertiary teachers and undergraduate students. Most secondary and tertiary educators, along with most undergraduate students, perceive that people in Greece are currently experiencing harm from global warming. However, this perception is significantly lower among upper secondary students. A correlation between participants' perceptions of psychological temporal distance for climate change and the four educational groups was found. The spatial and temporal disconnection of causes and effects which characterize complex systems, such as the climate, often causes major challenges in understanding the climate change effect among younger students (Roychoudhury et al., 2017).

Moreover, the time delay (temporal disconnection) may lead to personal frustration, as individuals' climate-friendly actions do not produce immediately visible impacts, which can reduce motivation to engage in such behaviours (Gifford, 2013).

Finally, participants mainly trust scientists, environmental organizations and teachers as sources of climate change information. This is a hopeful finding as previous research indicates that trust in scientists and environmental organizations is positively linked to climate-friendly actions (Cologna & Siegrist, 2020).

The results of this study indicate that it is very important to focus on secondary education. The findings highlight the need for designing risk communication techniques to reduce psychological distance and to engage secondary school students with climate change. It is very important to use trusted sources in this effort. Thus, appropriate activities could be designed at school with a cooperation of teachers, scientists and environmental organizations.

Moreover, since such studies can be used to design a roadmap aimed at raising public awareness about climate change, it seems very important to conduct them in other countries, and therefore different cultural contexts, as well.

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How Physics Teachers Think About Science – Physics Teachers’ Views Of Science Compared To Researchers’ Views

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Even though Nature of Science (NOS) and Scientific Inquiry (SI) are important aspects of the educational objectives for science lessons, as defined in the curriculum in Germany and other countries, research has shown that teachers often have insufficient professional knowledge in this area. Against this background, we have set up an outreach program in the Collaborative Research Centre ‘SFB1245: Atomic Nuclei: Fundamental Interactions to Structure and Stars’ at TU Darmstadt to identify and develop best practices for teaching NOS and SI at school. For this, teaching materials and handouts for teachers are being developed. In order to take into account the wishes and needs from a school perspective as well as the scientists’ views, both teachers and researchers are involved in the development of these materials. The accompanying study aims to determine the extent to which this collaboration positively influences the participating teachers’ ideas about NOS and SI. As a first step, we have conducted a survey about the views of secondary school physics teachers about NOS and SI and contrasted it against the researchers’ views in order to shed light on the baseline condition of our sample. In this contribution we will present and interpret the results of this survey. Building on this, we argue that the most relevant aspects of NOS and SI to address within the materials include the principle of research being guided by questions, as well as the constructive role of errors and interactions between researchers.

Keywords: Nature of Science, Scientific Literacy, Teacher Education

Introduction

Knowledge about Nature of Science (NOS) and Scientific Inquiry (SI) has been an educational goal since the beginning of the 20th century (Central Association of Science and Mathematics Teachers, 1907). Even today, this knowledge has not lost its importance and is regarded as being fundamental to scientific education in the sense of scientific literacy (OECD, 2017). Nevertheless, research has shown that students’ ideas about science are heterogeneous and often inadequate (Höttecke, 2012).

While knowledge about NOS and SI as educational goals should be fostered in the classroom, teachers themselves need to have the necessary knowledge about it in the first place (Kremer, 2010). However, research has revealed that teachers often have insufficient professional knowledge in this area (Billion-Kramer et al., 2020) and even if they have adequate ideas about it, this does not necessarily entail integration into their teaching (Bartos & Lederman, 2014). Reasons for this might be the complexity of the area and a lack of familiarity with the numerous aspects, as well as its inadequate consideration in teacher training, among other factors (Höble et al., 2004).

Against this background, we conclude that there is a need for teacher training as well as teaching materials and handouts for teachers to incorporate NOS- and SI-aspects into their classrooms. We have therefore set up a project to address this, as part of the outreach program in the CRC 1245 (Collaborative Research Centre ‘SFB1245: Atomic Nuclei: Fundamental Interactions to Structure and Stars’) at TU Darmstadt. This is a collaboration of various research groups, who work together on overarching issues and are funded by the German Research Foundation (DFG). In this project, a group of teachers and researchers (development group) will collaborate to develop these teaching materials and handouts. The accompanying study aims to determine the extent to which this collaboration positively influences the participating teachers’ ideas about NOS and SI.

In this contribution we will present and interpret the results of a preliminary study about the views of secondary school physics teachers on NOS and SI. We have conducted this study in the vicinity of our university, the sample including all teachers of the development group among others, to gain insight into the baseline conditions for our project. The aim of this study is to contrast the teachers' views against the researchers' views, and to derive the most relevant aspects of NOS and SI to address within the teaching materials and handouts.

Methods

For this purpose, we used the VOS questionnaire and the corresponding coding manual developed by Bächtold et al. (2021). It contains eleven items that cover eleven aspects (VOS 1 – 11) of NOS and SI, as shown in Table 1.

Table 1. Selected epistemological points - VOS questionnaire (Bächtold et al., 2021)

Aspect	Definition of the aspect	NOS/SI
VOS 1	Scientific knowledge is based on empirical support.	NOS
VOS 2	There is no single scientific method.	SI
VOS 3	Scientific investigations are motivated and guided by questions.	SI
VOS 4	Scientific knowledge is always tentative.	NOS
VOS 5	Science interacts with the socio-economic and cultural context.	SI
VOS 6	The empirical data on which scientific knowledge is based are always theory-laden.	NOS
VOS 7	The models built by the scientists are distinct from the empirical reality.	NOS
VOS 8	Errors may play a constructive role in the development of science.	SI
VOS 9	Interactions between scientists actively contribute to the construction and validation of scientific knowledge.	SI
VOS 10	Realism versus instrumentalism with respect to the role of models.	NOS
VOS 11	Relativism or rejection of relativism concerning the influence of the socio-economic and cultural context on the construction of scientific knowledge.	SI

These VOS-aspects are based on the NOS-aspects proposed by Lederman (Lederman et al., 2002) and the SI-aspects described by Lederman et al. (Lederman et al., 2014). Building on these frameworks, Bächtold et al. (2021) combined these NOS- and SI-aspects into an integrated set of dimensions capturing teachers' views of science and additionally introduced several new aspects, such as aspect VOS 8, which addresses the constructive role of errors, and aspect VOS 9, which focuses on interactions among scientists.

Following the coding manual by Bächtold et al. (2021), the qualitative coding of the questionnaire for each VOS-aspect is based on one to three items, whereby most items are each incorporated into the evaluation of several aspects. For VOS 1, 2, 4, 5, 7, 8 and 9 responses are assigned to one of the following categories: novice, rather novice, rather expert, expert, depending on the context or not interpretable. The aspects VOS 3 and VOS 6 are coded dichotomously as either novice or expert. For VOS 10, coding distinguishes between naïve-, balanced realism or instrumentalism, while VOS 11 is coded as strong-, rather strong-, rather moderate-, moderate relativism, rejection

of relativism or not interpretable. We translated the VOS questionnaire into German and conducted several 'think-aloud' sessions with students and researchers at our university (n=7). In addition, the questionnaire was administered to a group of university students (n=12) to pretest the translated instrument and to refine the corresponding coding manual. Additionally, the data were double-coded, followed by a coding reconciliation process.

After that, a digital version of the questionnaire was distributed via email to numerous secondary schools and teacher education institutions in the vicinity of our university between August and November 2024. In total, 58 teachers responded, of whom 42 completed the questionnaire and could therefore be included in the analysis. This group of teachers comprised 35 in-service physics teachers and seven pre-service physics teachers. Among these participants, 25 were male and 17 were female. For the analysis, only the questionnaires completed by in-service and pre-service physics teachers were considered, resulting a final sample of 42 physics teachers (17 female, 25 male). Seven in-service teachers and one pre-service teacher have a PhD.

In addition, the digital questionnaire was administered to researchers during a CRC 1245 workshop in November 2024. Due to time constraints, researchers were asked to respond only to items addressing selected aspects (VOS 1, VOS 3, VOS 4, VOS 7, VOS 8 and VOS 9) which were of particular interest for contrasting teachers' and researchers' views. In this group, 45 researchers participated, of whom 32 completed the questionnaire and were included in the analysis. The sample comprised 13 experimental physicists and 19 theoretical physicists, all specializing in nuclear and astrophysics as part of the CRC. The group included six project leaders (mostly professors), 18 PhD students, and eight researchers in other positions.

Results

Presentation Of Teachers' Results

The results of the analysis for the teachers are presented in Tables 2, 3 and 4 as rounded percentages, with absolute numbers given in brackets.

The evaluation shows that, particularly for the first aspect (VOS 1), the ideas of 43 % of the teachers are context-dependent, while 21 % are categorized as novices. This indicates that teachers hold naïve views on VOS 1, at least in certain contexts. The ratings for VOS 3 are also worrying, as 43 % of the teachers are categorized as novices, meaning that almost half of the teachers have inadequate conceptions of this aspect. Similarly, for VOS 6, nearly half of the teachers (48 %) demonstrate inadequate ideas. Aspect VOS 8 reveals that many teachers are categorized as rather novice (48 %), whereas only 41 % are classified as experts. For VOS 9, a substantial proportion of teachers (30 %) are also categorized as rather novice, indicating that many teachers lack adequate understanding of this aspect as well.

Table 2: Results VOS 10 aspect teachers in % (n=42) and the number in columns.

Naïve realism	14 (6)
Balanced realism	7 (3)
Instrumentalism	71 (30)
Others	7 (3)

Table 3. Results VOS Questionnaire teachers in % (n=42) and the number in columns.

	VOS 1	VOS 2	VOS 3	VOS 4	VOS 5	VOS 6	VOS 7	VOS 8	VOS 9
Not interpretable	12 (5)	0 (0)	2 (1)	0 (0)	0 (0)		0 (0)	12 (5)	0 (0)
Novice	21 (9)	0 (0)	43 (18)	0 (0)	7 (3)	48 (20)	14 (6)	0 (0)	0 (0)
Rather Novice	5 (2)	10 (4)		14 (6)	0 (0)		0 (0)	48 (20)	30 (16)
Depending on context	43 (18)	0 (0)		7 (3)	0 (0)		7 (3)	0 (0)	2 (1)
Rather Expert	0 (0)	29 (12)	55 (23)	52 (22)	0 (0)	52 (22)	57 (24)	0 (0)	31 (13)
Expert	15 (8)	62 (26)		26 (11)	93 (39)		21 (9)	41 (17)	29 (12)

Table 4: Results VOS 11 aspect teachers in % (n=42) and the number in columns.

Strong relativism	74 (31)
Rather moderate relativism	5 (2)
Moderate relativism	14 (6)
Rejection relativism	7 (3)
Not interpretable	0 (0)

The evaluation of the remaining aspects shows that the majority of teachers are categorized as instrumentalists for VOS 10 (71 %) and as strong relativists for VOS 11 (74 %).

A direct comparison between pre-service and in-service teachers reveals marked differences in aspects VOS 2, 3, 6, 8 and 9.

For aspect VOS 2, 43 % of the pre-service teachers are categorized as rather expert and an additional 43 % as expert, while 67 % of the in-service teachers are categorized as expert and only 24 % as rather expert. Regarding VOS 3, most pre-service teachers (71 %) are classified as

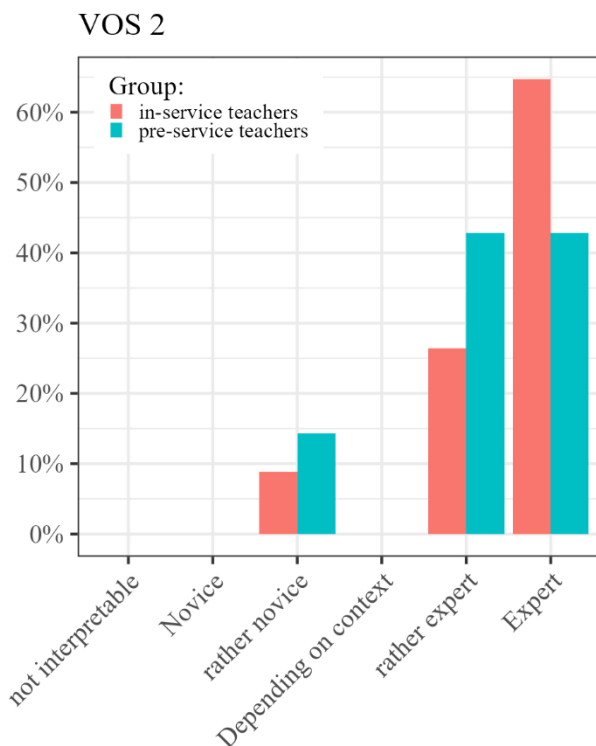
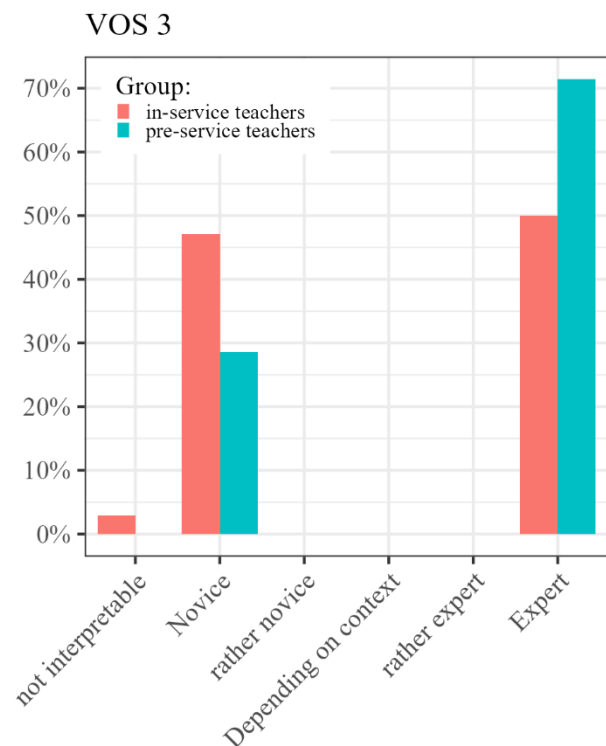
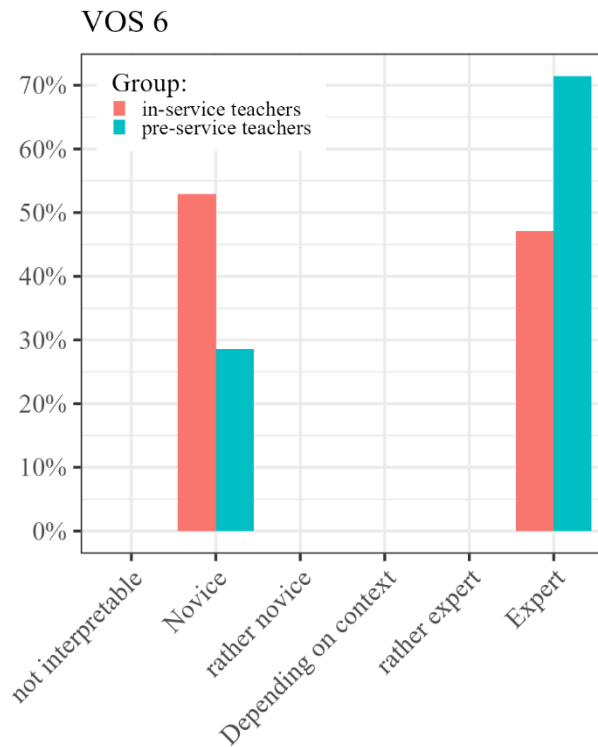
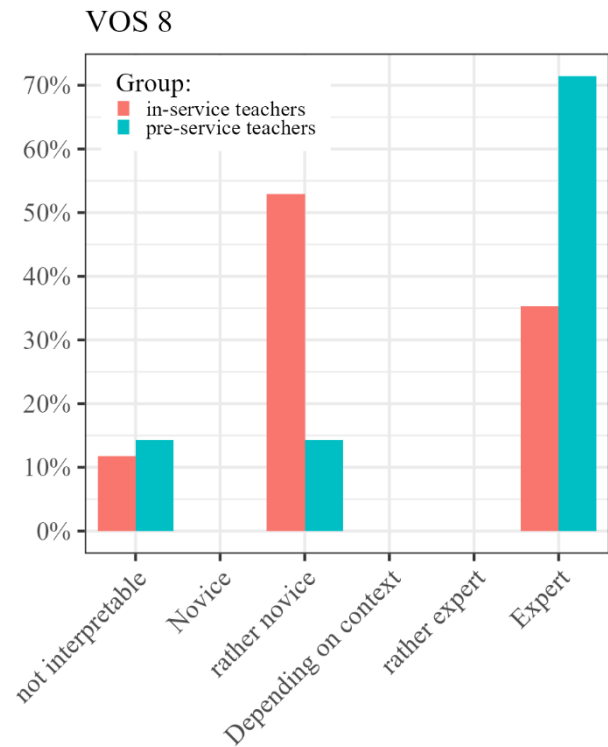
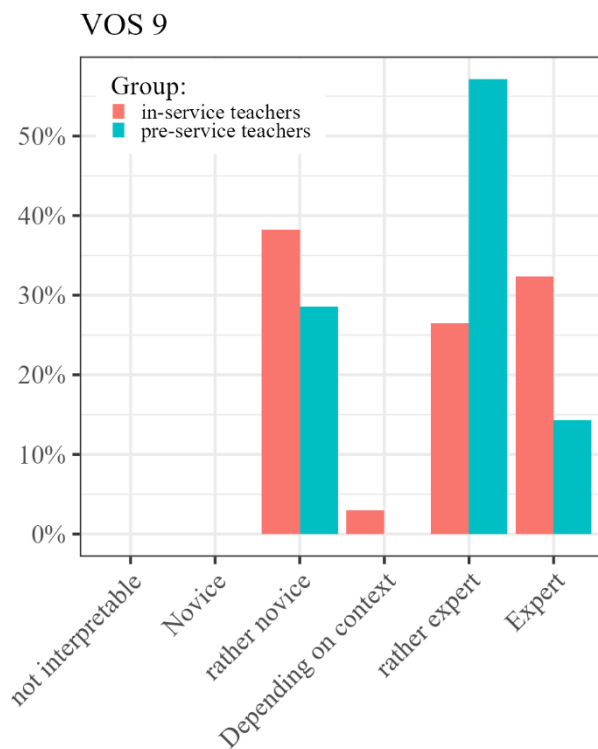
Figure 1: Results VOS 2.**Figure 2: Results VOS 3.**

Figure 3: Results VOS 6.**Figure 4: Results VOS 8.****Figure 5: Results VOS 9.**

experts, compared to only about half of the in-service teachers (52 %). For aspect VOS 6, again 71 % of the pre-service teachers are categorized as experts, while more than half of the in-service teachers (55 %) are categorized as novices.

A similar pattern emerges for VOS 8: 71 % of the pre-service teachers are categorized as experts and only 14 % as rather novice, while 52 % of the in-service teachers are categorized as rather novice and only 36 % as experts.

A different distribution can be observed for VOS 9. Among pre-service teachers, 29 % are categorized as rather novice, 57 % as rather expert, and only 14 % as expert. In contrast, among in-service teachers, 36 % are categorized as rather novice, 27 % as rather expert, and 33 % as expert.

Interpretation Of Teachers' Results

The analysis of the results indicates that many teachers show limited familiarity with several aspects of the VOS framework. Across multiple dimensions, a considerable proportion of teachers were categorized at lower levels, suggesting that key characteristics of scientific practice are not consistently represented in their responses. Overall, the findings point to a fragmented and context-dependent understanding rather than a comprehensive and integrated view of scientific investigations.

In general, the results suggest that many teachers have had little direct engagement with scientific research practices themselves. Their reported understanding appears to be shaped primarily by school-based experiences and formal instructional settings rather than by active involvement in research processes. Furthermore, the contact with scientific concepts during teacher education seems to have been only partially aligned with the broader epistemic aspects addressed in the framework, with a stronger focus on content knowledge and procedural routines than on overarching features of scientific inquiry.

Differences between in-service and pre-service physics teachers were observed, indicating variation in how these aspects are understood at different stages of professional development. While pre-service teachers tended to demonstrate more advanced understandings in several areas, in-service teachers also showed greater familiarity with some selected aspects, potentially reflecting professional experience. However, these differences remain descriptive, as the present data do not allow firm conclusions about their underlying causes.

Overall, the results suggest that substantial portions of both groups lack a fully developed understanding of central characteristics of scientific practice. This points to a need for further consideration of how such aspects are addressed in teacher education and professional development, particularly with respect to connecting theoretical exposure during studies more closely to the core epistemic features of scientific research.

Comparison Of Teachers' Views To Researchers' Views

To enable a more differentiated interpretation of the results, the teachers' views were compared with researchers' views of science.

The results of the analysis for the researchers are shown in Table 5.

Table 5. Results shortened VOS Questionnaire CRC-researchers in % (n=38) and the number in columns.

	VOS 1	VOS 3	VOS 4	VOS 7	VOS 8	VOS 9
Novice	38 (12)	17 (5)	0 (0)	12 (3)	0 (0)	0 (0)
Rather Novice	9 (3)		4 (1)	0 (0)	3 (1)	0(0)
Rather Expert	6 (2)		43 (12)	58 (15)	0 (0)	26 (7)
Expert	13 (4)	83 (24)	32 (9)	27 (7)	90 (26)	70 (19)
Depending on context	22 (7)		21 (6)	4(3)	0 (0)	4 (1)
Not Interpretable	13 (4)		0 (0)	0 (0)	7 (2)	0 (0)

The findings show that for aspect VOS 1, even researchers received relatively few expert ratings, while a considerable proportion (38 %) were categorized as novices. One possible explanation is, that the researchers' responses to one of the relevant items were highly specific to a particular case and therefore did not fully align with the coding scheme applied in the analysis. An analysis of the shortened VOS questionnaire completed by CRC-researchers working in experimental or theoretical physics reveals marked differences for aspect VOS 1. Theoretical physicists show a balanced distribution between notice and expert (21 % each) as well as between rather novice and rather novice (5 % each). In contrast, experimental physicists exhibit a clear tendency toward novice categorizations, with 62 % categorized as novice and no expert categorizations observed.

For aspects VOS 3 and VOS 4, researchers show a higher proportion of expert ratings compared to teachers. The result for VOS 7 is almost identical for researchers and teachers. A substantial

difference is evident for VOS 8, where the majority of researchers are categorized as experts, while about half of the teachers are categorized as rather novices. Similarly, nearly all researchers are categorized as experts or rather experts for VOS 9, while 40 % of the teachers are classified as rather novices.

Discussion

Regarding limitations, we acknowledge that the sample size of this study is relatively small. Nevertheless, the preliminary findings allow for several important conclusions relevant to the present project. The results indicate that the views of many teachers on aspects of the nature of science (NOS) and scientific inquiry (SI) are inadequate, especially for aspects VOS 1, 3, 6, 8 and 9, teachers' results showed ideas that do not reflect reality. For VOS 3, 6 and 8 pre-service teachers demonstrate more informed views than in-service teachers.

These aspects address key characteristics of scientific practice, namely that scientific knowledge is based on empirical support (VOS 1), that scientific investigations are motivated and guided by questions (VOS 3), that scientific knowledge is based on theory-laden empirical data (VOS 6), the constructive role of errors in scientific progress (VOS 8) and the importance of interactions among scientists in the development of science (VOS 9).

The results therefore suggest that pre-service teachers possess a more advanced understanding in these areas, highlighting the need for targeted interventions particularly for in-service teachers. The relevance of this is further underlined by the fact that in-service teachers have few opportunities to gain deeper insight into current research and scientific processes that they can incorporate into their teaching.

Furthermore, the views of researchers, especially those working in experimental physics, are not consistently categorized as experts in the present analysis, despite their professional expertise in NOS- and SI-aspects due to their work. The results for this question suggest some limitations in the coding manual, and interpretations based on it should be approached with caution. Revising the manual could help provide a clearer assessment of the underlying aspect.

Based on these findings, we argue that there is a clear need for further teacher training as professional development opportunities, as well as for the development of teaching materials and handouts to support teachers in addressing these topics in the classroom. Such materials should place particular emphasis on aspects VOS 3, 6, 8, and 9 by highlighting the interplay between theoretical and experimental physics, providing insights into the productive role of errors in scientific processes, and emphasizing the collaborative nature of scientific research. Within this context, the CRC provides an excellent framework for the implementation of such initiatives.

Acknowledgement

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Fighting Fake News In Science Project: An Action Research Study Involving Brazilian Students, Teachers And Academics

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Contemporary society faces challenges in combating Fake News (FN), especially in science-related topics. During the COVID-19 pandemic, FN intensified globally, especially in Brazil, where the political misinformation, spread widely via social media, impacts collective health. The lack of media criticism and scientific literacy exacerbated the issue, highlighting the need for educational initiatives. In response, a Participatory Action Research (PAR) project titled “Fighting Fake News in Science” was launched, involving academics, teachers, and students from a public university and a school in Rio de Janeiro. Over one school year (2022), the team followed PAR’s cyclical stages—Plan, Act, Reflect, Evaluate—to address misinformation about COVID-19. The methodology involved: establishing relationships and a common agenda with the team; collaboratively deciding on issues, research design, ethics, and accountability; Planning, scheduling and implementing an action plan, working together to collect and analyse data, and disseminating our findings. The action plan involved four phases where students chose, studied and analysed four FN (e.g., alkaline foods cure COVID-19) using an information disorders framework. Guided by teachers, they conduct inquiry-based activities to deconstruct FN through scientific experiments, fostering critical thinking and collaborative problem-solving. The findings were disseminated via Instagram® (@meninas_fakenews), a lecture, a workshop, and a local conference. The project achieved significant impact, engaging over 200 participants and inspiring students, particularly girls, to consider careers in Science. Testimonials highlighted the transformative experience, with students expressing gratitude for the opportunity to lead, learn, and grow. The project underscores the importance of empowering communities to combat misinformation and promote scientific understanding.

Keywords: Science Education. Misinformation. Participatory Action Research.

Introduction

Contemporary society is marked by the constant and diverse flow of information facilitated by the internet, which has democratised knowledge but also brought challenges regarding the credibility of information (Flanagin & Metzger, 2000). Fake News (FN) and manipulative reporting have gained notoriety in recent years and are often labelled as one of the biggest threats to democracy (Hinds, 2019). According to Tandoc et al. (2017), FN can be defined as false and sensationalist information disseminated as news. For Wardle and Derakhshan (2017), FN, conspiracy theories, clickbait, rumours, and hoaxes are part of a more complex framework, information disorders.

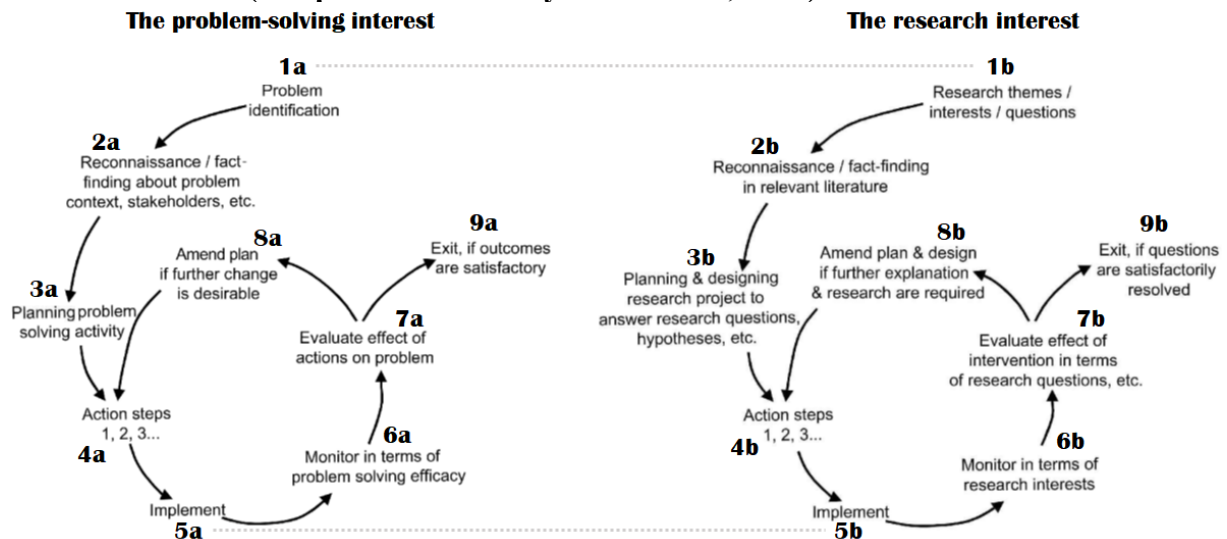
In Brazil, during the COVID-19 pandemic, the dissemination of FN intensified, representing a danger to public health, as many people accepted and shared information without critical thinking (Islam et al., 2020). The FN spread at the beginning was characterised by political content regarding misinformation about the number of cases and deaths and prevention measures and treatment, mainly disseminated through WhatsApp® and Facebook® social media (Barcelos et al., 2021).

The lack of scientific knowledge contributes to people spreading misinformation, especially regarding Natural Science disciplines, Chemistry, Physics and Biology. Scientific literacy, a polysemic term commonly used to describe an understanding of science and its societal applications (Laugksch, 2000), is crucial to empowering citizens to reckon with and combat these

untruths, promoting an adequate understanding of science and its practices. This highlighted the importance of educational initiatives. In this context, academics, high school teachers and students engaged in a project entitled Fighting Fake News in Science aimed to empower the local community to become protagonists in fighting science-based FN. This paper aims to present the Project, conducted through a Participatory Action Research (PAR) study.

Action research is an approach that integrates action and research, aiming to address practical problems while generating new knowledge (McNiff, 2013). More specifically, PAR is focused on addressing a specific local issue and attempts to empower participants or bring about social change. PAR is a cyclical process with four general phases: Plan, Act, Reflect and Evaluate. The outcomes from one cycle are used as the basis for continued exploration of practice in the following cycle. The PAR *Fighting Fake News in Science* Project was conceptualised and conducted through the dual cycle process (Figure 1) adapted from McKay and Marshall (2001), focused on both problem-solving (Steps 1a-9a) and research interests (Steps 1b-9b).

Figure 1: The dual cycle process in action research, focused on problem-solving and research interests (Adapted from McKay & Marshall, 2001).



The four stages of the PAR Project were:

- 1st Stage (PLAN) – Steps 1, 2 and 3: Examining the situation, identifying the problem, and planning the activities.
- 2nd Stage (ACT) – Steps 4 and 5: Obtaining the necessary information to answer the question, defining which sorts of data are needed and how to collect them, and developing and implementing an action plan.
- 3rd Stage (REFLECT) – Step 6: Monitoring, analysing, interpreting, and sharing the data.
- 4th Stage (EVALUATE) – Steps 7, 8 or 9: Determining improvements based on a new standard, and creating new plans to implement changes.

Results And Discussion

To select a community setting and co-researchers who agree to explore a feasible Project, we establish relationships and a common agenda to collaboratively decide on issues. The team included: two academics/full professors (Chemistry and Science Education) from the Fluminense Federal University (UFF), four high school teachers (Biology, Chemistry, Portuguese and Sociology) from a public school in Rio de Janeiro, the school's Principal, who was a Master's

student in Science Education at UFF, one undergraduate student at UFF (pre-service Chemistry teacher) and three senior high school students.

The Project was conducted through five-hour monthly meetings during one Brazilian school year (January-December 2022). The first task (*January*) was to decide on the issue the research would focus on. The students conducted an online survey with the local school community (students, parents, staff, teachers), asking them to differentiate between true and fabricated news and justify their answers. Almost 85% of the community could not distinguish between fact and false information; the COVID-19 news was the most difficult for them. Major justification relies on a lack of media criticism (e.g., not checking the information source) or science literacy (e.g., not understanding the vocabulary). Similar results were found in the recent Organization for Economic Cooperation and Development report (OECD, 2024), in which Brazil and Colombia rank lowest in identifying false content online.

Then, the team decided (*February*) to focus the problem on COVID-19 FN, involving Chemistry and Biology contents, defining the question they would like to answer: *How to improve media criticism and science literacy about COVID-19 at our school?* The academics gathered some previous research on the topic (e.g., Puig et al., 2021) and shared it with the team in a meeting (*March*). Mediated by the Sociology teacher, the students discussed the potential benefits and pitfalls of the Project and how to deal with political sensitivities around the issue (e.g., some parents disliked the theme and did not allow their children to participate in the Project).

The next meeting (*April*) was aimed at scheduling the action plan, which was organised into four phases:

- Phase 1: Choosing a COVID-19 FN to work with – one for each student.
- Phase 2: Understanding the FN according to the disorder information framework.
- Phase 3: Conducting an inquiry-based activity to deconstruct the FN, improving scientific grasp.
- Phase 4: Reporting the results to the team and creating ways to disseminate our findings to the local community.

The team gathered (*May*) to answer some critical questions (Kindon et al., 2007): *What data collection methods do we plan to use? What ethical issues may be raised by our methods? What technical skills do team members need training in? What written or visual materials must we prepare to support data gathering? How will the team incorporate reflection and iteration into our process? How do we record and store our data?* We decided to audio record the dialogues between the team, complemented by research annotations and collect all types of products the students might develop. The academic trained the science teachers to create and apply inquiry-based activities in a classroom setting. All the students and their parents signed the Informed Consent Form.

The next five meetings were used to implement the four-phase action plan. Using social media and websites, the high school students, mentored by the undergraduate student, chose the FN they wanted to study (**Phase 1, June**): (1) Alkaline foods, such as lemon, pineapple, garlic and dandelion, are effective in fighting coronavirus as they alter the blood pH. (2) 99% alcohol is more effective against coronavirus than 70% alcohol. (3) Alcohol gel is ineffective against coronavirus as it contains gelatine, which keeps your hand wet for longer, so we recommend

using vinegar instead. (4) Tonic water fights coronavirus because it contains quinine, which is similar to chloroquine.

Following, the students gathered with the Portuguese teacher to better understand the FN messages and their impact on our lives (**Phase 2, July**). Using Wardle and Derakhshan's (2017) framework, they classified the type of disorder, identified their elements (agent, message and interpreter), used source-checking and fact-checking mechanisms and proposed what technology companies, government, civil society, and education ministry could do to fight FN in our country. They made panels and essays (Figure 2) to present their results.

Figure 2: Panels and essays used by the students to present their choices and studies during Action Phase 2.



The Chemistry and Biology teachers developed inquiry-based activities (Figure 3) to engage the students in problem-solving for each FN (**Phase 3, August-September**). The elements of the inquiry-based activity were (Cheung, 2007): presenting a problem situation, identifying prior knowledge, proposing a question to be answered, establishing a hypothesis, conducting laboratory tests, analysing data, explaining the results based on theory and making some conclusions. They finished this phase by presenting scientific reports.

Figure 3: Inquiry-based activity created to deconstruct the first Fake News: “Alkaline foods are effective against coronavirus”.

Problem Situation	Laboratory (continuing)
The pH of the new coronavirus varies between 5.5 and 8.5. Eating foods with a pH higher than this value is enough to fight the virus. A healthy human body has a blood pH that is neither too acidic nor too alkaline — the mark varies between 7.35 and 7.45. It is necessary to eat more alkaline foods, which are above the pH level of the virus, so that it alters the blood pH and can be fought in the body. Foods such as lemon, orange, tangerine, mango, garlic and pineapple are effective against the coronavirus.	B) Preparing the pH indicator based on red cabbage <ul style="list-style-type: none"> ✓ Chop 2 to 3 red cabbage leaves by hand. ✓ Add to the grill with 25 mL of hot water. ✓ Mash with the pestle until you obtain a dark purple extract. ✓ Filter using the funnel and filter paper. ✓ Set aside the extract
Prior Knowledge Ask students about what they know about the concepts of acidity, basicity and the pH scale. How do you know that a food is acidic? Can a sweet or bitter food also be acidic? What measurement indicates the acidity of a substance? What does it mean for something to be alkaline? What do you understand by pH? Would you know what the pH of the blood is? Is there any substance in the blood that alters its pH?	C) Building the pH scales <ul style="list-style-type: none"> ✓ Place two rows with 5 micro test tubes each. ✓ Write down the pH values of 2, 5, 7, 10, 13 in each tube. ✓ Fill the tubes with 2 mL of each ready-made solution. ✓ Dip a pH indicator strip into each solution and compare it with the colour scale in the box. ✓ In the first row, place 2 mL of the red cabbage extract in each test tube – use the Pasteur pipette. ✓ In the second row, place 3 drops of the phenolphthalein pH indicator in each test tube. ✓ Write down all the results in a Table.
Problem How can you determine if a food is alkaline? Will this food be able to change the pH of your blood?	D) Testing pH test in various foods <ul style="list-style-type: none"> ✓ Separate 10 micro test tubes and label them with numbers 1 to 10 containing the foods to be tested. ✓ Testing should be done using any of the indicators chosen from the group along with juice or a mixture of the food with a small amount of water ✓ Record the results in a Table.
Hypotheses Record your answers to the questions in the “Problem” in your notebook.	Research and Conclusion What types of pH indicators were used? Qualitative (information) or quantitative (number)? What are the turning points (pH at which there is a colour change) of red cabbage and phenolphthalein? Was the prediction you initially made about the pH of the food in the Fake News correct according to the results obtained? What happened to the buffer solution when a strong base was added? Considering that blood is also a buffer solution, what would happen to the pH of our blood when we eat alkaline foods? And acidic foods? Research which substances present in red cabbage and phenolphthalein work as pH indicators. Research which substances present in each food tested are responsible for their acidic or basic/alkaline characteristics. What incorrect scientific information was conveyed in the Fake News analysed? What is the impact of believing in it? How can it be combated?
Laboratory Materials: Pipette with distilled water; Glass beakers; Erlenmeyer flask; 25 test tubes on a stand; Test tube Pasteur pipettes; Grail and pistil; Glass funnel; Filter paper; Universal support and ring; Phenolphthalein solution; Ready-made solutions of pH 2, 5, 7, 10 and 13; pH indicator strip 0 to 14; Hot water; Various foods: red cabbage, lemon, avocado, garlic, mango, tangerine, pineapple, orange, egg, lemon soda, coffee, milk. Procedures Procedure: A) Predicting the acidity of foods <ul style="list-style-type: none"> ✓ Divide into groups with three or four students. ✓ Individually, predict the acidity of the foods listed: Lemon, Avocado, Garlic, Mango, Tangerine, Pineapple, Orange, Vinegar, Sparkling water, and Coffee. ✓ Organise your answer in a Table - write A if you think the food contains acidic substances, write B if you think it has a basic (or alkaline) character, and write N if you think the food has a neutral pH, that is, neither acidic nor basic. ✓ When finished, compare your predictions with your groupmates. 	

The whole team planned the dissemination of the results (**Phase 4, October**) and evaluated the Project as a group and as individuals. The team choose three ways to communicate our findings (Figure 4): (a) to create an Instagram page (@meninas_fakenews) to post scientific information on COVID-19 and fighting FN (*November*); (b) to deliver a lecture and a workshop (*November*)

for the school community on how to identify information disorders and to use online fact-checkers; (c) to organise a local conference (*December*) to present the Project results and to conduct inquiry-based activities for other students.

We produced 22 posts on Instagram® with social media metrics: 192 followers, 1,223 likes, 235 shares and 202 comments. More than 200 people attended the lecture, workshop and conference during the Project. The students gave testimonials regarding the impact of the Project on their lives: *“The Project was wonderful, a great experience!”* (S1); *“The Project gave girls like me, who aren’t very interested in Science, the opportunity to participate in such a surreal experience. It was an incredible initiative to encourage women to engage in this field. Unfortunately, opportunities like these are rare but very necessary”* (S2); *“I am extremely grateful and fulfilled because it was a wonderful and unforgettable experience. The best part was visiting UFF and meeting kind teachers. I hope you can carry out more projects like these in schools”* (S3). For the undergraduate student, *“It was a unique opportunity to take the lead in making decisions about a project and at the same time conduct teaching activities with high school students as a mentor”* (S4).

Figure 4: Students engaged in disseminating the Project findings through a lecture, a workshop, laboratory tests and a conference.



Final Remarks

The PAR *“Fighting Fake News in Science”* Project involved a multidisciplinary team of university academics and the local school community to build knowledge and insights on science-based FN about COVID-19. There is evidence of improving scientific literacy and media criticism through inquiry-based activities and social media scientific dissemination. Major limitations were found due to politically sensitive topics in a country psychologically shaken by threats to democracy and collective health. The Project ended in 2024, but its developments continue to be observed in new research, teaching and extension projects.

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Pre-service Primary Teachers Evaluate Media Sources On Climate Change

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The widespread dissemination of misinformation about climate change poses significant challenges for individuals, particularly non-experts such as pre-service primary teachers, in discerning reliable information. The present study explores the strategies employed by pre-service primary teachers to evaluate the credibility and validity of media sources related to climate change. Adopting a qualitative research design, a series of activities focusing on the recognition of deceptive tactics, the assessment of source expertise, and the understanding of media gatekeeping was developed and implemented in a form of a teaching experiment. Data was collected through audio-recorded sessions involving 14 pre-service primary teachers, working in groups of two. The findings revealed that while participants frequently emphasized source's reputation and background, they experienced difficulties in evaluating the relevance of authors' expertise and in considering the social aspects of science such as the role of scientific consensus. These findings highlight the need to integrate such aspects in initial teacher education programs in order to support the development of pre-service teachers' science media literacy.

Keywords: climate change, misinformation, science media literacy

Introduction

Climate Change Misinformation & The Need For Science Media Literacy

In recent years, there has been a growing international acceptance that climate change is one of the most urgent and challenging socioscientific issues due to its environmental, political, economic and social implications (IPCC, 2023; Leiserowitz et al., 2011). While the scientific community has reached a consensus regarding the scientific aspects of climate change and the role of anthropogenic activities in exacerbating the phenomenon, various controversial yet seemingly convincing information relating both the causes and the extent of climate change continues to be widely disseminated either through broadcast media or social media (e.g. IPCC, 2023; Leiserowitz et al., 2011). This kind of information often questions both the anthropogenic nature of climate change and the effectiveness, economic and political implications of the proposed response and adaptation measures (e.g. Whitmarsh et al., 2013).

Several interrelated factors explain why non-experts tend to believe or share such misinformation. These include cognitive dispositions that bias individuals' thinking, particularly their pre-existing beliefs, as well as social influences and online interactions that lead to isolated communities, commonly described as echo chambers or filter bubbles, which reinforce existing views and limit exposure to diverse perspectives. In addition, identity-protective thinking may lead individuals to accept misinformation that aligns with their cultural, political, or religious identities (e.g. Pimentel, 2025; Siani & Gennari, 2025). Finally, the systematic use of misinformation strategies (*deceptive tactics*) that cast doubt on well-established scientific findings, question relevant expertise and institutional credibility, emphasize scientific uncertainty, repeat false claims making them seem true (*illusory truth effect*), and employ emotionally charged language (e.g. Lewandowsky et al., 2021) further reinforces non-experts' susceptibility to misinformation.

Within this context, tackling climate change misinformation requires a multifaceted approach. On the one hand, it involves policy initiatives and regulatory measures targeting online platforms, as well as adjustments in science communication and journalistic practices aimed at improving the quality of scientific information. On the other hand, it necessitates educational approaches that prepare individuals to critically evaluate scientific information encountered in the media. Focusing on this latter aspect, the need to equip non-experts with competencies for assessing the reliability and trustworthiness of information sources related to climate change becomes particularly relevant (e.g. Pimentel, 2025; Siani & Gennari, 2025; Osborne & Pimentel, 2023). The development of such competencies includes a. the understanding of epistemic dependence on experts and the role of empirical evidence in scientific processes; b. the interaction with media sources which involves skills and strategies for the identification of the source expertise, the identification of credible gatekeepers, the recognition of deceptive tactics; and c. the understanding of the role of personal pre-existing beliefs in the way individuals interpret information as well as the counter-balancing role of scientific consensus (e.g. Pimentel, 2025; Allchin, 2023; Osborne & Pimentel, 2023; Allchin, 2022; Höttecke & Allchin, 2020). Therefore, science education needs to emphasize the development of these competencies—commonly referred to as science media literacy—to effectively address and respond to the growing misinformation crisis related to contemporary socioscientific issues, such as climate change (e.g., Allchin, 2022; Höttecke & Allchin, 2020; Osborne & Pimentel, 2023).

Teachers' Science Media Literacy

With regard to teachers' evaluation strategies, recent research has highlighted a gap between teachers' digital skills and the depth of their information-evaluation practices. Although pre-service teachers frequently engage with online sources and demonstrate familiarity with digital tools, their evaluation of scientific information often remains superficial, focusing on surface-level indicators rather than epistemic or social - institutional features of science (e.g., Bellocchi et al., 2025). At the same time, there is limited empirical evidence on the specific strategies teachers employ when evaluating media sources related to socioscientific issues. The literature therefore underscores the need to enrich initial teacher education with science media literacy-oriented approaches, so that teachers can develop robust evaluation practices and gradually transfer these competencies to science classrooms (e.g., Fernández-Carro et al., 2024).

Based on the above, the purpose of the present study is to explore the way pre-service primary teachers interact with and evaluate media sources regarding contemporary socioscientific issues such as climate change. Hence, the research question that leads the present study is “*What strategies do pre-service primary teachers employ in order to evaluate media sources regarding climate change?*”.

Methods

Participants

The participants of the study were 14 pre-service primary teachers (PPTs) who were in the second year of a 4-year bachelor degree in primary education. The participants had attended a compulsory course on fundamental concepts of physics as well as a course on fundamental principles of science education. The participants were divided into seven groups.

The Teaching Experiment

In the present study, the teaching experiment method was employed, which is an interview organized as a learning situation (Komorek & Duit, 2004). This method is particularly appropriate

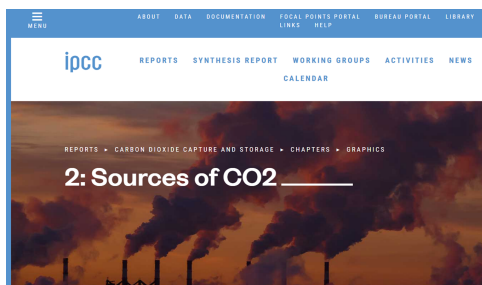
for exploratory studies, as it allows researchers to examine participants' reasoning processes as they unfold during engagement with the learning activities. The teaching experiment was structured in five phases. Initially, pre-service primary teachers (PPTs) engaged in an introductory activity designed to elicit their prior criteria for evaluating media sources. The subsequent phases emphasized (i) the recognition of deceptive tactics, (ii) the evaluation of credibility across different media gatekeeping mechanisms, and (iii) the assessment of source expertise (Allchin, 2022; Allchin, 2023; Höttecke & Allchin, 2020). In the final phase, participants applied these competencies to support evidence-based reasoning and decision-making in a new authentic situation.

The teaching experiment was implemented through the development of five learning activities. The instructional context involved a renewable energy source company accused of providing deceptive data regarding the level of carbon dioxide emissions associated with its products. Within this scenario, the company's lawyer had access to a variety of information sources and was required to decide which sources could be used to build company's defense strategy. PPTs were asked to assume the role of the lawyer's assistants and were responsible for evaluating the credibility and validity of the available sources. The content of each activity is described below:

Activity 1. PPTs Orientation & Engagement

PPTs are presented with four snapshots of media sources (a scientific report, an online newspaper, a blog post, and an Instagram post) (Figure 1) addressing climate change and are asked to rank the sources in order of increasing validity, explicitly mentioning the criteria used.

Figure 1. Snapshots of media sources.



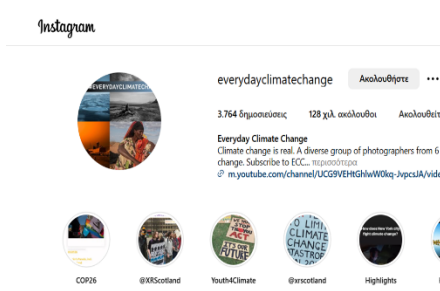
(a) Scientific report



(b) Online newspaper



(c) Blog post



(d) Instagram post

Activity 2. PPTs Familiarization With Common Deceptive Tactics

PPTs are provided with an article and a rubric outlining five common deceptive tactics and are asked to identify whether these tactics are present in the text. The aim for PPTs is to categorize the article as a high or low quality source and to justify whether it should be considered credible evidence in the case.

Activity 3. PPTs Familiarization With Review Mechanisms

PPTs are initially presented with three different media sources (an academic paper, an online newspaper, and an Instagram post) communicating the same information by the same author and are asked to comment on the validity of each source. Subsequently, PPTs discuss the mediation of professional gatekeepers across different media types and rank the sources in order of increasing validity to determine which source should be provided to the court.

Activity 4. PPTs Familiarization With Criteria For Assessing Source Expertise.

PPTs are presented with five cards describing different source profiles based on educational background, professional and academic experience, participation in organizations and institutions, and other relevant responsibilities. PPTs are asked to select the most suitable profile to trust in relation to a renewable energy source dilemma and to justify whether this source should be presented to the court. Additionally, PPTs are asked to reflect on what further information they would require in order to finalize their decision.

Activity 5. Application Of Knowledge And Skills To A New Context.

PPTs are provided with an authentic TikTok video featuring a scientist expressing views on renewable energy sources. PPTs are asked to decide whether the source should be trusted and used as evidence in court, providing justification for their decision.

Data Collection And Analysis

The teaching experiment was conducted during one 90 – minute session for each group of participants and data was collected accordingly through audio recordings of each session.

Due to the exploratory nature of the study, qualitative methods of content analysis were used (Bryman, 2017). The category system developed to analyse the criteria employed by PPTs when evaluating media sources is presented in Table 1 and includes six broad categories: (i) source expertise, (ii) source features, (iii) source motivations, (iv) source attitude towards science, (v) source communication strategies, and (vi) source interface.

Table 1. Categorization of evaluation criteria.

Categories	Subcategories
Source expertise	Status
	Background & expertise
	Credentials & reputation
Source features	Review mechanisms
	References
	Authenticity
Source motivations	Conflicts of interests
	Purpose of the source
Source attitude towards science	Questioning of scientists & formal institutions
	Alignment with scientific consensus
	Scientific uncertainty
	Illustration of empirical data
Source communication strategies	Use of emotional language
	Illusory truth effect
Source interface	Web domain
	Layout

Results

With regard to the results of the study, data analysis revealed that PPTs predominantly refer to source expertise when evaluating a media source related to climate change as well as to the source

features and attitude towards science. In contrast, references to source motivations such as conflicts of interests or communication strategies including the use of emotional language, were less often. Finally, it seems that the technical characteristics of online sources do not constitute a primary criterion in PPTs' source evaluation strategies. The following table (Table 2) presents the absolute frequencies of PPTs' references to the different evaluation criteria.

Table 2. Results regarding PPTs evaluation criteria.

Categories	Subcategories	References	Total
Source expertise	Status	35	123
	Background & expertise	43	
	Credentials & reputation	45	
Source features	Review mechanisms	48	78
	References	23	
	Authenticity	7	
Source motivations	Conflicts of interests	13	44
	Purpose of the source	31	
Source attitude towards science	Questioning of scientists & formal institutions	24	76
	Alignment with scientific consensus	10	
	Scientific uncertainty	10	
	Illustration of empirical data	32	
Source communication strategies	Use of emotional language	24	30
	Illusory truth effect	6	
Source interface	Web domain	7	12
	Layout	5	

By focusing on source expertise, PPTs tended to emphasize the source's credentials, such as their collaborations, the reputation of their home institutions, and the source's educational background or professional experience. For instance, one PPT noted: *"He {the source} has a PhD and he is now working at a well-known institution while he has recently published three papers. So, I think that this profile is the most reliable one"*. Interestingly, source status alone was sometimes considered sufficient for establishing validity, even without mentioning specific background or experience. For example, one pre-service teacher mentioned: *"She is a researcher, and we unquestioningly trust researchers and scientists"*. Thus, although PPTs frequently referred to source expertise, closer examination of their reasoning suggests that such references often relied on indicators of scientific status or authority rather than on the relevance of expertise to the issue under examination.

Concerning source features, PPTs mainly highlight the review mechanisms employed in different media sources, such as peer review or editorial review. For instance, one PPT explained: *"In scientific reports or academic papers, there is a scientific committee responsible for checking the research process, whereas on platforms like Instagram or TikTok, no one verifies what is published—anyone can share their views and beliefs"*.

Regarding sources' attitude toward science, PPTs often emphasized that the illustration of empirical data - such as diagrams or data visualizations - enhances a source's perceived validity. Less frequently, they recognized that questioning scientists or the broader scientific consensus is an indicator of reduced credibility. For instance, one PPT noted: *"Here, I think that he casts doubt on something that nine out of ten scientists have agreed on. So, I think that I won't take this source into account"*.

The findings reported here illustrate the ways in which PPTs evaluated media sources related to climate change.

Discussion And Conclusions

Based on the study findings, PPTs seem to apply credibility criteria that have been identified in the literature when evaluating media sources on climate change and they are generally able to distinguish between high- and low-quality sources (e.g. Pimentel, 2025; Allchin, 2023; Osborne & Pimentel, 2023). In particular, PPTs tend to rely heavily on source expertise - a finding consistent with recent empirical research involving pre-service science teachers in Australia (e.g. Bellochi et al., 2025) - as well as on the presence of review mechanisms and the use of empirical data representations. However, relying solely on diagrams, numerical data and tables may be misleading for PPTs, since such elements can mirror the structure of professional scientific reports without necessarily reflecting robust scientific practices (e.g. Allchin, 2022; Pimentel, 2025). From a science media literacy perspective, this fact highlights the importance of moving beyond surface indicators of credibility toward evaluation strategies that take into account how scientific knowledge is produced and validated. Additionally, the emphasis placed on a source's status indicates that PPTs tend to accept scientific authority, without considering whether a scientist's expertise is directly relevant to the issue under examination – an aspect widely recognized as crucial in the evaluation of scientific information. Finally, PPTs rarely identified or even tried to identify potential source conflicts of interests, and they paid limited attention to the role of scientific consensus when assessing the credibility of information. These findings suggest limited familiarity with the social-institutional aspects of science, which are central to informed evaluation of socioscientific information (e.g., Pimentel, 2025; Erduran & Dagher, 2014) and suggest that PPTs approach source evaluation primarily through indicators that are associated with scientific authority and credibility of an individual source rather than broader scientific processes.

In conclusion, the present findings highlight key areas for supporting PPTs' development of science media literacy competencies. In particular, teacher education programs could place greater emphasis on the social and institutional dimensions of science, such as the role of scientific consensus, conflicts of interest, and the relevance of expertise to a specific scientific or socioscientific issues, in order to strengthen PPTs' science media literacy. Accordingly, future work may focus on the design, development, and evaluation of teaching resources informed by these insights, as well as on further examination of how to support the development of more robust evaluation strategies among PPTs and how such competencies are transferred to classroom practice.

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The Deep Structure For Teaching And Learning Socioscientific Issues

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The present theoretical contribution proposes a comprehensible framework for teachers who wish to integrate socioscientific issues (SSI) into their science classes. To this end, we conduct a theoretical argumentation that demonstrates a relationship between visions of scientific literacy and competencies for teaching and learning science through SSI. Following this, we discuss possible approaches to teaching SSI and emphasize the need for a theoretical foundation in collective pedagogical content knowledge for SSI. Our approach involves combining learning objectives and teaching structures to promote moral development in students working with SSI, based on existing theoretical models. The connection between learning and teaching is facilitated by the combination of so-called 'basis-models', which aim to foster communication and assessment competencies. By structuring science classes in this way, teachers can be empowered to effectively manage a scaffolding of lessons. This enables teachers to clarify their role in enabling argumentations and promoting students' moral development within SSI.

Keywords: SSI, moral-development, basis-models

Introduction

The modern world is undergoing a transformative era marked by profound changes in sociopolitical, economic, and environmental spheres, as well as in the established social order. These aspects are interrelated, often controversial, and require complex analysis for comprehensive understanding. When included in science classes, topics such as climate change are referred to as socioscientific issues (SSI). SSI are defined as “the deliberate use of scientific topics that require students to engage in dialogue, discussion, and debate” (Zeidler & Nichols, 2009, p. 49). Engaging in argumentation and discourse on SSI should promote the development of critical assessment competencies, as decision-making is heavily influenced by the abundance of both accurate and misleading information. As a result, the significance of SSI in education has grown (Chen & Xiao, 2021). Some national curriculum standards have already incorporated explicit topics, such as climate change (Guerrero & Sjöström, 2024). Given these contemporary and essential demands, it is crucial to focus on the role of teachers, who must guide students in navigating and engaging in complex argumentation and discourse. Although there is a considerable amount of research and educational materials on SSI, a comprehensive theoretical pedagogical framework is still lacking (Viehmann et al., 2024). To address this gap, we propose integrating an established learning-teaching model into the discussion — the basis-model-theory (Oser & Baeriswyl, 2001) — and applying it to SSI. Building on this model, we develop a theoretical framework that is grounded in the deep structures of learning and teaching processes aimed at fostering students' moral development while addressing SSI.

Aim: Developing A Theoretical Approach

In this contribution, we aim to address the following question: Which deep structures underpin the learning and teaching of socioscientific issues? To explore this question, we implement a theoretical approach by using an accessible syllogism:

- First premise: Learning about SSI involves recognizing a dilemma, using criteria to argumentatively address the dilemma, and perceiving the resulting moral development.

- Second premise: Moral development requires teaching SSI, where planning includes learning objectives, appropriate content that can be acquired through self-regulation, and well-guided interactions.
- Conclusion: Teaching SSI should encourage learners to develop their moral understanding in relation to a dilemma. Through moderation and self-regulation, learners are able to formulate arguments. Development is perceived through teacher-learner interactions. The combination of two so-called basis models (Oser & Baeriswyl, 2001) provides the scaffolding for teaching and subsequently learning SSI.

First Premise: Learning Through SSI Promotes Moral Development

There is an apparent consensus regarding the main learning goal of science education in school, which is defined by the term '*scientific literacy*'. This refers to the knowledge of science that should empower individuals to solve problems within scientific domains, facilitate critical thinking, and enable participation in complex discussions about technology and sustainability. The definitions provided by Roberts for scientific literacy form a basis of these widely accepted understandings (Roberts, 2007, p. 766). Chen and Xiao noted that despite this consensus, the concept of scientific literacy has been interpreted differently within the national curriculum standards of various countries (Chen & Xiao, 2021, p. 11).

In their examination of the connection between scientific literacy and SSI, Valladares and Sjöström reviewed the interpretations and visions of scientific literacy, emphasizing the need for developing learning objectives. These range from "Vision I," which relates to traditional content-based teaching, through "Vision II," which involves applying science to SSI contexts, to "Vision III," where science facilitates engagement in action and transformation (Sjöström, 2024; Valladares, 2021). Such engagement could be understood as an externalization of acquired argumentation and evaluation competencies. In summary, learners should become competent outsiders, especially in today's era of misinformation (Osborne & Pimentel, 2023).

Recently, the concept of '*science identity*' has been developed from the previous construct of scientific literacy, as a parallel dimension to 'scientific knowledge' and the 'competencies' (OECD, 2023). This relatively new concept aims to evaluate young people's connection to science. Within this dimension, one sub-dimension explicitly considers environmental awareness and the integration of personal and scientific values applicable to SSI contexts, as defined in the PISA framework (ibid.). These concerns should be incorporated into critical decision-making processes and sustainable practices.

In addition, Kashyap (2026) recognizes the relationship between science identity and scientific literacy, proposing a pathway that links the two. According to Kashyap, science identity can grow into scientific literacy through the "capacity to adopt meta-positions" and the "awareness of the dialogical self" (ibid., p. 12). His approach involves developing the concept of literacy as the coordination of "value-laden and socially consequential" concepts within a dialogical competence (ibid., p. 18).

In our case, in Germany, the discourse on science literacy does not play a predominant role, but rather the competencies that show similarities, such as the ability of using scientific knowledge for decision making (Kauertz et al., 2012). The term '*competencies*' refers to Weinert's definition, which involves long-term learning processes that address "cognitive and (in many cases) motivational, ethical, volitional, and/or social components" (Weinert, 2001, p. 62). Over the past decade, science competencies have been operationalized into standards divided into four competency areas: content knowledge, scientific enquiry, communication and assessment (i.e. evaluation) (Neumann et al., 2010).

The new national educational standards explicitly include interdisciplinary objectives in communication and assessment areas, which can be contextualized with reference to SSI (KMK, 2024). In these contexts, students must navigate various criteria based on scientific and personal perspectives to formulate well-grounded arguments that lead to decisions and subsequent reflections on consequences (ibid.). Such argumentations are shown to play a central role as a vehicle for reasoned claims, a view accepted internationally (Dawson & Carson, 2017). For this aim, students must learn how to construct an argument, identify and select criteria, and apply them accurately in language. The abilities involved are part of communication competence. Beyond those skills, students must also evaluate dilemmas and develop well-reasoned personal viewpoints on interdisciplinary topics. Furthermore, when making decisions, they connect their competence with their performance (Blömeke et al., 2015). This process is closely linked to assessment competence and is similar to a form of “functional scientific literacy” (Zeidler & Sadler, 2023, p. 920).

As they evolve their personal beliefs through these evaluation processes, it can be assumed they undergo moral development (Oser & Baeriswyl, 2001), as defined by the theory of moral development (Kohlberg & Hersh, 1977). Zeidler adds, in this context, the term of moral inquiry, as “an activity aimed at advancing virtue when confronted with conflicting or unclear moral judgements” (Zeidler, 2024, p. 41). Moral inquiry can be addressed through controversial SSI after creating an ethical disequilibrium that awakens “empathy, sympathy, and compassion” (ibid., p. 40). Furthermore, an “empathetic dissonance” is necessary to trigger a motivational response (ibid., p. 47). In this way, learners can develop their morality by engaging in dilemma discussions that facilitate the realization of context-related moral reasoning through both cognitive and motivational dimensions (Nunner-Winkler, 2007). Immersive experiences, such as place-based SSI instruction, promote conceptual and moral development in students (Herman et al., 2021).

Second Premise: Teaching SSI Requires The Involvement Of Morality

Regarding pedagogical structures for dealing with SSI, Saunders and Rennie developed a model for ethical inquiry, which they investigated qualitatively with a small sample of teachers (Saunders & Rennie, 2013). The model proposes nine sequential stages: “(1) teacher preparation, (2) students engaging with the broad issue, (3) students understanding the science behind the issue, (4) individual reflection on the issue/values exploration, (5) group discussion of specific issues, (6) deciding on specific questions or controversial statements, (7) ethical thinking about the questions or statements from various ethical frameworks, (8) ethical decision-making and justification, (9) action/evaluation/decision” (ibid., p. 270). Teachers highlighted that the model demonstrates cohesiveness and flexibility and aids students in critical thinking. The study emphasized the need to develop pedagogies that move away from transmissive approaches, advocating for teachers to guide students' self-regulated research and debates. To achieve this, “teachers may require assistance in developing criteria that support them in assessing issues where there are no right or wrong answers” (cf. ibid., p. 269). In this noteworthy approach, the need for argumentative moral development is also recognized.

Macalalag et al. (Macalalag et al., 2020; Johnson et al., 2020; Minken et al., 2021) developed, implemented, and investigated a professional development course for teaching SSI in STEM classes, which considers the following steps: “(A) Identifying the issue, (B) Scientific phenomenon, (C) Engage in STEM modeling, (D) Consider issue system dynamics, (E) Employ reflective scientific scepticism, (F) Compare and contrast multiple perspectives, (G) Elucidate own position / solution” (Minken et al., 2021, p. 123). The study showed that the participant teachers increased their knowledge and instructional skills regarding SSI. However, they

demonstrated lower levels of content knowledge related to the SSI and of scientific scepticism (ibid.).

The results of Macalalag et al.'s study are consistent with Bayram-Jacobs et al. (2019). In Bayram-Jacobs et al.'s research, teachers learned to adapt SSI materials in a professional development course. In that study, all materials used the same scaffolding: "Presenting a dilemma, recap or learn scientific knowledge needed for the task, and a student's SSI task which is a simple, structured activity to resolve the dilemma" (ibid., p. 1213).

Both Macalalag and Bayram's theoretical background resides in PCK. Building on the theoretical approach of Magnusson et al. (1999), the presented studies qualitatively illuminate some interactions between the components of PCK for teaching SSI: "Knowledge of Instructional Strategies for Teaching SSI, Knowledge of assessment of SSI, Knowledge of curriculum, Knowledge of learning context, and Knowledge of students' SSI learning" (Chang & Park, 2020, p. 425).

A final model, called Values and Knowledge Education, combines the mentioned perspectives in a very complete approach that aimed at solving dilemma situations: "(0) Preparation of the students and pupils, (1) Introduce dilemma, (2) First decision, (3) First arguments, (4) Exchange experience and asking about missing information, (5) Looking for evidence, (6) Exchange information, (7) Second arguments (dilemma discussion), (8) Synthesis of information, (9) Repeat 4 through 8 if necessary, (10) General synthesis, (11) Generalization" (Patry & Weyringer, 2022, p. 29). Studies conducted using this framework demonstrate positive development of transformative processes by participants (ibid.).

In Germany, a group of science educators from different science education disciplines with a focus on assessment competence, has presented a model comprising six stages: (1) Perceiving, (2) Analysing, (3) Arguing, (4) Weighing, (5) Deciding, (6) Reflecting (Langlet et al., 2022). Each stage is further divided into several substages, except for the last one. The publication also provides useful exercises and tips, such as separating steps into three types of implementations: to perceive and analyse; to argue; and to weigh, decide and reflect. Once again, the progression of arguments, decisions, and reflections occurs in clearly defined steps, supporting the moral development of students.

Finally, research has shown that interdisciplinary collaboration among teachers in schools is an effective way to develop interdisciplinary content and establish pedagogical knowledge of SSI, thereby promoting the intended moral development through argumentation (Kutluca, 2021; Viehmann et al., 2024).

Conclusion: Bringing Teaching And Learning Together Through Deep Structures

A Selection Of 'Basis-Models' For Designing The Deep Structure

As highlighted in the previous paragraphs, moral development can be identified as the fundamental learning objective for students engaging with SSI. Moreover, fostering moral development in science classes demands teaching plans that ensure effective communication and assessment, particularly in the context of SSI. Both, assertions and recognized needs require a theoretical approach that depicts the deep structures of learning and teaching SSI, with a clear emphasis on promoting moral development.

Oser and Baeriswyl proposed a theory of 12 so-called basis-models for the deep structure design of teaching processes, drawing on psychological and educational theories (Oser & Baeriswyl, 2001). These basis-models are derived from diverse learning objective types and consist of

various steps of teaching and learning that form chains. The theory does not allow any steps to be skipped or omitted. In addition, basis-models can be combined sequentially or interwoven. Research has shown that planning lessons using a selection of three basis-models ('Concept Building', 'Learning Through Discovery', and 'Problem Solving') can enhance students' learning outcomes in science classrooms (Geller et al., 2014). However, basis-models for the competency areas of communication and assessment have not been sufficiently investigated and are not included in this selection, as they target developmental processes beyond content-based or inquiry learning (Hümbert-Schnurr et al., 2022). Instead, they aim to foster multi-perspective, valid arguments, as discussed in the previous paragraphs.

An analysis of the remaining nine basis-models reveals that competencies concerning assessment and communication can be enhanced through different learning objective types and corresponding choreographies. Two of these models are particularly well-suited because their learning goal types are similar to those of SSI (Oser & Baeriswyl, 2001, p. 1046):

- “Development as the Aim of Education” (DAE), with the learning goal type “deep structure transformation, such as moral judgment” in five steps.
- “Hypertext Learning” (HL), with the learning goal type “reordering and revaluing information bits” in six steps.

The basis-models DAE and HL can be combined as follows to achieve the learning objectives described in the right column of Table 1b. Starting from the corresponding steps, the resulting learning processes foster engagement with conflicts (DAE1) and exploration of positions in complex contexts (DAE2). During the self-regulated phase (DAE3), students search for information independently or in groups to support arguments. Oser predicted moral development in this step (ibid.). Subsequently, with teacher moderation, students analyse and weigh these arguments (DAE4). The process culminates in reflection on personal development (DAE5), which contributes to moral development. The HL basis-model can be introduced in the step (DAE3) if the lesson also focuses on critical thinking, for example. In that case, students must first select the topic (HL1), then structure the information (HL2), define the objectives (HL3) and determine their learning approach (HL4). After that, they execute the self-determined path (HL5) and, finally, they manage the results (HL6).

Comparison Of Models

The presented combination of basis-models reflects the fundamental characteristic of our approach, which underscores the deep structure. The following tables illustrate this characteristic by comparing the stages outlined by Saunders & Rennie, Macalalag et al., Patry & Weyringer and Langlet et al. (as presented above) with those of our own approach.

Table 1a. Comparison of first two approaches presented in this contribution.

	Saunders & Rennie	Macalalag et al.
(-)	(1) Teacher preparation	
(I)	(2) Students engaging with the issue	(A) Identifying the issue
(II)	(3) students understanding the science behind the issue	
(III)	(4) individual reflection on the issue/values exploration (5) group discussion of specific issues (6) deciding on specific questions or controversial statements	(B) Scientific phenomenon (C) Engage in STEM modeling (D) Consider issue system dynamics
(IV)	(7) ethical thinking about the questions or statements from various ethical frameworks (8) ethical decision-making and justification	(E) Employ reflective scientific skepticism (F) Compare and contrast multiple perspectives
(V)	(9) action/evaluation/decision	(G) Elucidate own position / solution

Table 1b. Comparison of following two approaches and our own.

	Patry & Weyringer	Langlet et al.	Our Approach
(-)	(0) Preparation of students		
(I)	(1) Introduce dilemma	(1) Perceiving	1. Dilemma presentation (DAE1)
(II)	(2) First decision	(2) Analyzing	2. Exploring controversial positions (DAE2)
(III)	(3) First arguments	(3) Arguing	3. Exposure to advance arguments (DAE3)
	(4) Exchange experience and asking about missing information		1. Topic selection (HL 1)
	(5) Looking for evidence		2. Structuring information (HL2)
	(6) Exchange information		3. Defining objectives (HL3)
			4. Learning approach (HL4)
			5. Path execution (HL5)
			6. Result management (HL6)
(IV)	(7) Second arguments (dilemma discussion)	(4) Weighing	4. Argument Analysis (DAE4)
	(8) Synthesis of information		
	(9) Repeat (4)-(8) if necessary		
(V)	(10) General synthesis	(5) Deciding	5. Reflection (DAE5)
	(11) Generalization	(6) Reflecting	

The selection and combination of basis models reveal an underlying structure for planning and analysing teaching sequences for SSI. Additionally, this approach's coherence with others has been emphasized. One strength of the present approach is its simple, user-friendly structure, which supports learning processes. Furthermore, rather than providing a solution to a dilemma, these learning processes encourage investigation and debate surrounding it. Therefore, fostering communication and assessment competence should be a long-term process that incorporates similar strategies and deep structures in several SSI lessons on different topics. Furthermore, the selected basis models focus on the self-regulated development of students' science identities and beliefs, which teachers moderate. As shown above, this is a starting point for moral inquiry. In conclusion, this approach explicitly fosters interactions between at least three components of SSI-PCK: knowledge of instructional strategies for teaching SSI, knowledge of the learning context, and knowledge of students' SSI learning.

Limitations, Future Direction, And Conclusion

One difficulty when working with the basis-models is that the functions of the different steps may be misunderstood (Krabbe et al., 2015). In this case, it is important to explicitly define the stages of the deep structure applied to SSI and develop materials based on the proposed guidelines. This would allow for the extrapolation of the SSI framework to a smaller order of magnitude.

Additionally, when considering the practical implementation of controversial debates, developing teaching strategies for scaffolding in the last two steps presented in Table 1b (right column) seems necessary. In this context, the basis-model 'Learning Through Realistic Discourses' could be considered for the deep structure of these learning and teaching processes.

Understanding the underlying deep structures of teaching and learning, as proposed in our approach, is essential for identifying better future research directions in the field of SSI. The selected basis-models are based on psychological and pedagogical research and consider the development of students' knowledge and morality. They are also more process-oriented than product-oriented, making them more coherent with the desired competencies and activities.

The present approach could make SSI more practical for teachers due to its simple structure, which makes planning single science lessons easier, for example. However, future empirical analyses of existing SSI materials, as well as the development of new materials, are necessary. These materials could then be used in professional development programs for pre-service and in-service teachers. The effectiveness of these training courses should be studied.

For science teachers, this knowledge could provide with insight into managing SSI processes, enabling them to motivate students to move away from transmissive pedagogies and facilitate personal growth.

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Socioscientific Issues And Laboratory Work In Lower Secondary School - Some Challenges

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Previous research suggests socioscientific issues (SSI) can improve student interest in science, increase learning of content and strengthen scientific literacy. Most of this research, however, is focused on the level of the teaching unit. There is relatively less on how different activities within the teaching units suit an SSI approach. In this study we investigate the teaching and impacts of a module focused on food production and population growth in lower secondary school (age 15). We employ a mixed-methods design, combining classroom observation and interview with a pre-post difference-in-differences design. Quantitative results ($n=3876$) are promising with medium-sized effects on situational interest and content specific self-efficacy. Qualitative results based on 90 hours of observation and interviews with students and teachers, however, indicate that socio scientific issues work well with non-experimental activities, but less so with experimental lab activities. The laboratory parts of the module tend to be more focused on proving the usefulness of suggested solutions than on allowing students to investigate their own hypotheses. This has consequences for the depth of discussions and limits the types of evidence it is possible to bring forward by students. We suggest that this reflects not only limitations in the design of the module but also points to broader challenges in integrating student laboratory work within SSI-based teaching, particularly for younger students.

Keywords: Socioscientific Issues, Laboratory Work in Science, Secondary School

Introduction

Socioscientific issues (SSI) are ill-structured problems with no simple solutions that involve political, ethical, social aspects as well as scientific knowledge. They are often controversial and contentious issues for society, requiring the use of evidence from science as well as other disciplines, and often include a debate between students about possible ways of action, moral reasoning and judgement (Evagorou & Nielsen, 2019; Evagorou & Dillon, 2020; Tidemand & Nielsen, 2017). SSIs can be based on dilemmas from many domains such as environmental sustainability (e.g. ecological systems, food production), resources and energy (e.g. clean energy development), technology (e.g. artificial intelligence and large language models), medicine and neurosciences (e.g. gene therapy) (Evagorou & Nielsen, 2019; Wan & Bi, 2018).

Previous research has suggested the use of socioscientific issues in science education can promote student interest in science, increase learning of content, as well as their scientific literacy. On this basis, many scholars have argued for the integration of SSI into science teaching (Sadler & Dawson, 2012; Çalik & Wiyarsi, 2024). At the same time, the literature highlights a number of challenges associated with SSI-based teaching, including resistance to pedagogical innovation, the inherent complexity of the topics, and the demand for specialized teacher training (Tidemand & Nielsen, 2017; Zeidler & Sadler 2023; Ke, Sangori, Sadler & Friedrichsen 2020).

In recent years, empirical research on socioscientific issues (SSI) has expanded considerably. However, much of this literature has focused on analysing the effectiveness of complete teaching units or instructional sequences, rather than examining the role of individual activities within those units. As a result, comparatively little research has addressed how specific classroom

activities are designed and how well they align with the principles of SSI-based teaching, particularly at educational levels below upper secondary or tertiary education (see e.g. Sadler, 2004; Sadler & Dawson, 2012; Çalik & Wiyarsi, 2024; Zeidler & Sadler, 2023; Nolan & Zeidler, 2025; Karisan et al., 2018; Sá-Pinto et al., 2022). Moreover, relatively few studies have investigated how younger students engage with the SSI approach and different types of activities, such as experimental laboratory work, within such a framework (Evagorou & Nielsen, 2019).

To address these gaps, the present study examines how fifteen-year-old students in lower secondary school engage with and make sense of classroom activities within an SSI-based teaching module. By focusing on classroom processes during implementation, the study provides a more fine-grained understanding of how SSI-oriented activities function for younger students across different activity types. The following research questions guided the study:

- In what ways do lower secondary students participate in an SSI-based teaching module?
- How do experimental laboratory activities and non-experimental activities function within an SSI-based teaching approach?

Research Method And Data

The study is based on a mixed-methods approach combining classroom observation and interviews with a pre-post difference-in-differences design based on survey data from students. Although this paper draws on the quantitative part of the study for necessary context and background, this paper primarily is concerned with data from the qualitative component.

The module under study consists of a five-week in-school activity followed by a one-day out-of-school activity for some classes. The module integrates content from physics/chemistry, geography, and biology.

The approach in the quantitative component of the study is reported elsewhere (Bergquist & Osmundsen, in press). The qualitative component is based on case studies of eight lower secondary school classes in which the module was implemented. Cases were selected using a maximum-variation sampling strategy to support analytical transferability, based on criteria such as teacher experience and school socio-economic context. Qualitative data collection took place during the first part of the 2023/24 school year (August–December 2023).

The SSI framework served as an explicit analytical lens throughout the qualitative study. Prior to classroom data collection, a desk study of the module's learning materials was conducted, during which all activities were analysed against key characteristics of SSI-based teaching, including the extent to which activities foregrounded socioscientific problems, supported student deliberation, and facilitated discussion of the possibilities and limitations of scientific and technological solutions. This analysis informed both the observation focus and the subsequent interpretation of classroom practices.

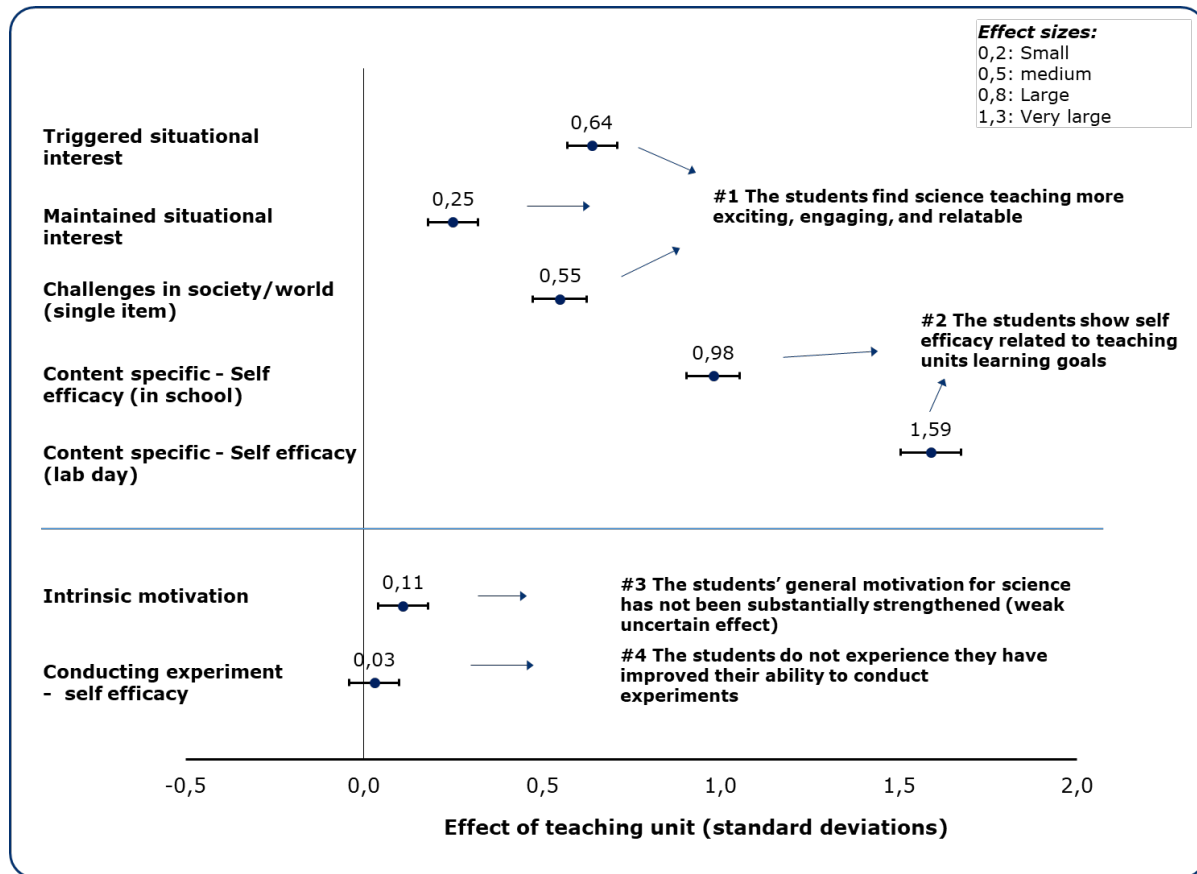
The main body of qualitative data consists of approximately 90 hours of naturalistic classroom observation across the eight cases. During observations, detailed field notes were taken and subsequently transcribed. In addition, focus group interviews were conducted with 3–5 students in each class at selected points during the course and with one focus group per class at the conclusion of the module. Students were selected to capture a range of perspectives, including variation in engagement with the module.

Finally, semi-structured interviews were conducted with each of the eight participating teachers at the end of the course to elicit their reflections on implementing the SSI-based module. All interviews were audio-recorded and transcribed verbatim.

Findings

Figure 1 shows the results of the quantitative part of the study.

Figure 1. Impacts on student interest, motivation and self-efficacy.



Note: Standardized effect estimates from regression models, with cluster-robust standard errors at the class level. Lines indicate 95% confidence intervals around point estimates ($n=3,876$ observations).

Source: Bergquist and Osmundsen (in press)

Results showed improved student interest and self-efficacy. Students who were taught the module were more interested in and showed a greater desire to participate, compared to students in the control group (Triggered situational interest, medium effect: 0.64 SD) (see Figure 1). Additionally, students found that the teaching unit could be related to daily lives to a high degree. (Sustained situational interest, small effect: 0.25 SD) With regards societal or global challenges, there was a medium effect (0.55 SD).

However, the results also showed that there was only a weak uncertain effect on intrinsic motivation for science (0,11 SD) and that it didn't improve their ability to conduct experiments (se Figure 1).

These largely positive results are supported by the qualitative results; however, they also show a more nuanced picture. The module consists of many different teaching activities that can roughly be divided into two groups: non-experimental and experimental activities. All of the latter take place in a laboratory setting. We observe a marked difference in student engagement in the non-experimental and experimental activities.

A non-experimental activity that figures prominently in the module is a turn-based game, where the students develop a fictitious country. In each round, they invest within four categories: agriculture, fertilizer, education and behaviour. As they have limited resources, they must prioritize their investments. After each turn, they can see the consequences of their choices for the country's food needs, food production, CO₂ emissions and school attendance. In their

prioritization, they must use knowledge about the country's demography, climate and soil conditions, which they know from a previous activity. The game gives the students a lot of autonomy as there is no 'right answer' and students truly get the opportunity to investigate and select solutions to deal with the socioscientific issue.

We see that students participate in the game with an exploratory approach, for example by studying data about the population and climate of the country while discussing investments. We also see students trying to figure out which real country their fictional country most likely resembles and then research everything about that country to strengthen their actions in the game. Furthermore, we see that students engage in arguments with each other for and against different investments from each other. For example, they relate to scientific evidence when they discuss possibilities and limitations of investments and to their consequences for the economy, climate, environment and people. This behaviour shows that the students at the same time have an exploratory, independent and creative approach and can relate to the socioscientific issue. A teacher describes the link between the game and the socio-scientific issue like this: *"The game is clearly the one activity who make the students aware of factors that you have to take into account: Why can't you just make sure that now we make investments that give lots of food? That won't solve the problem. It just results in more population growth and even greater food needs"*. In addition to working competently with the problem, students work with commitment. Even if the game is very simple in design, the students identify with the country they are playing. As one student puts it: *"It's a great responsibility to be responsible for the development of a whole country. And we're only 15 years old!"*.

The module also includes several experimental lab activities. In these activities the students show less engagement and less competence compared with the gaming activity. Examples of experimental lab activities include when students examine properties of catalytic reactions, as catalysis is part of the production of artificial fertilizers, which is one of the possible solutions to increase food production. They investigate, via hypothesis formation and variable control, how much nutrient is leached from the soil of their fictitious country when crops are exposed to chemical fertilizers. Both these activities are closed-ended with a fixed protocol that the students must follow.

We see that the students in the experimental lab activities participate in a results-oriented way, with a focus on solving the task 'correctly' and finding 'the right answer'. We also see uncertainty among students, as they often seek the teacher's confirmation as to whether they are on the right path. We don't see indications of the students connecting their work in the experimental lab activities with the problems or the challenges of their fictional country. The students' commitment and participation are directed towards the lab work itself, and reflection on results is not linked to the problem or to what they can use their results for in relation to the development of their countries. Nor do they reflect on how what they have investigated relates to the production or use of chemical fertilizers. As one teacher puts it: *"It is quite demanding for the students to succeed with the lab activities, and this puts the socioscientific issue in the background"*. At the same time, we also noticed that the teachers rarely made explicit connections between the experimental laboratory activities and the socioscientific issue or the students' fictional countries.

Discussion

In conclusion, we find that non-experimental activities generally support the intentions of SSI-based teaching, whereas experimental laboratory activities appear less successful in this regard, suggesting a possible challenge in SSI-based teaching. We argue that this is not only due to limitations in the design of the module under study but also points to broader challenges in integrating student laboratory work within SSI-based teaching, particularly for younger students.

These challenges may be related to safety considerations and students' limited laboratory competencies, which are often associated with age and maturity in lower secondary school. As a result, meaningful laboratory activities can be difficult to design in ways that allow students sufficient autonomy to explore and evaluate different solutions. Consequently, experimental laboratory activities tend to be relatively close-ended, with fixed protocols for students to follow, which may conflict with key principles of socioscientific issues. Rather than enabling students to explore alternative solutions experimentally, laboratory work often focuses on confirming the solution proposed in the module or by the teacher. This finding has broader implications for the integration of SSI-based teaching alongside traditional science education, as many curricula emphasise not only data collection and analysis but also students' engagement with laboratory work.

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Argument Development Through Socioscientific Issue-Based Teaching: Asteroid Mining With Gifted Students

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This study examines how socioscientific issue-based instruction supports the argument development processes of gifted secondary school students. The research was conducted within the context of asteroid mining, a contemporary socioscientific topic that encompasses scientific, ethical, and societal dimensions. The teaching process was structured based on the Socioscientific Issues Teaching Framework developed by Friedrichsen et al. (2016). The activities were enriched in line with Renzulli's (2014) Triple Enrichment Model to support the cognitive and affective characteristics of gifted students. Furthermore, socioscientific dilemma cards, developed based on Yacoubian's (2015) Critical Thinking and Nature of Science Framework, were used to deepen students' critical thinking and awareness of the nature of science. The research was conducted using a case study design, adopting a qualitative research approach. The study group consisted of 30 gifted secondary school students studying at a Science and Art Centre in Turkey. The implementation process lasted six weeks and consisted of four main activities. The data sources were written arguments developed by the students; the data were examined through descriptive analysis, taking into account the structural characteristics of the arguments. The findings show that the arguments developed by the students can be grouped into three levels: simple, advanced, and complex. It was determined that a significant proportion of the students demonstrated reasoned thinking skills, but the number of students developing complex arguments was limited. The results reveal that socioscientific issue-based instruction supports gifted students in developing arguments by evaluating scientific, ethical, and social dimensions together; however, it also highlights the need for explicit and structured argumentation instruction to develop more complex argumentation skills.

Keywords: argumentation, asteroid mining, gifted students

Introduction

Today, rapid, complex and often unpredictable developments in science and technology mean that it is no longer sufficient for individuals to simply possess knowledge of scientific concepts (Hodson, 2011). Instead, it is becoming increasingly critical for individuals to be able to evaluate this knowledge within social, ethical, political, and economic contexts (Jasanoff, 2004; OECD, 2018). The increasing visibility of the social consequences of scientific knowledge production necessitates a rethinking of the aims of science education (Sadler, 2004). In this context, one of the fundamental goals of science education is to ensure that students are not merely consumers of knowledge but grow into individuals who can make reasoned and informed decisions about complex, controversial, and uncertain scientific issues (Sadler, 2011; Zeidler, 2014).

Socioscientific issues, which lie at the intersection of scientific knowledge and social values and inherently involve uncertainty, ethical dilemmas, and multiple perspectives, provide a strong pedagogical context for this goal (Sadler & Zeidler, 2005; Zeidler et al., 2009). These topics reveal that scientific knowledge is not a fixed, unchanging and indisputable structure, but rather a value-laden process negotiated within social contexts (Kolstø, 2001; Sadler, 2004). In this respect, socioscientific issues enable students to develop a more critical and realistic understanding of the nature of science (Lederman, 2007; Yacoubian, 2015).

Socioscientific issue-based teaching is an approach that aims to holistically develop students' critical thinking, scientific reasoning, and argumentation skills, and it is gaining increasing attention in the field of science education (Evagorou & Osborne, 2013; Zeidler et al., 2009). This approach seeks to transform students from passive recipients of information into active participants who evaluate scientific evidence, consider opposing views, and develop reasoned arguments (Sadler et al., 2007). Research shows that teaching processes conducted in socioscientific contexts strengthen students' ability to relate scientific knowledge to everyday problems and increase their motivation to learn (Aikenhead, 2006; Ratcliffe & Grace, 2003).

Argumentation is a fundamental scientific practice that involves individuals defending their claims with evidence, evaluating alternative views, and reaching reasoned conclusions (Kuhn, 1991; Toulmin, 1958). In the context of science education, argumentation is recognised as a central learning practice that makes students' scientific thinking processes visible and encourages critical evaluation (Erduran et al., 2004; Sampson & Clark, 2008). Numerous studies have demonstrated that argumentation-based learning environments deepen students' conceptual understanding and support their scientific reasoning skills (Berland & Reiser, 2009; Osborne et al., 2004).

Argumentation-based learning environments, particularly for gifted students, offer significant opportunities for supporting higher-order cognitive skills and deep thinking (VanTassel-Baska, 2013; Zohar & Dori, 2003). These students have the potential to evaluate multiple perspectives, think abstractly, and engage in critical inquiry when faced with complex problems (Renzulli, 2014; VanTassel-Baska, 2013). However, for this potential to emerge, learning environments must be consciously structured and students must be guided towards active intellectual production (Subotnik et al., 2011).

Space mining, and asteroid mining in particular, has emerged as a contemporary socioscientific topic in recent years, drawing attention for its scientific, economic, and political dimensions (Cockell, 2011; Sonter, 1997). Asteroid mining encompasses numerous controversial elements, such as the sustainable use of natural resources, space law, technological limitations, global economic inequalities, and ethical responsibilities (Elvis, 2014; Milligan & Schwartz, 2020). This multidimensional structure makes addressing the topic in the context of science education pedagogically meaningful (Sadler, 2011; Zeidler et al., 2005).

With these characteristics, asteroid mining provides a rich learning context that enables students to discuss not only the question of 'what is possible?' but also 'what should be done?' (Sadler, 2011; Zeidler & Nichols, 2009). This context supports students in questioning the limits of scientific knowledge, the societal consequences of scientific progress, and value-based decision-making processes (Osborne et al., 2004).

The main aim of this study is to examine how socioscientific issue-based teaching conducted in the context of asteroid mining reflects on the argument development processes of gifted students. In this regard, the main research question is formulated as follows:

RQ1. How do gifted students participating in a socioscientific issue-based learning environment develop arguments regarding a controversial socioscientific issue such as asteroid mining?

Within the scope of this question, the structural characteristics, levels of complexity, and perspectives contained in the arguments developed by the students are examined.

Theoretical Framework

This study is built upon three fundamental theoretical pillars: the teaching approach to socioscientific topics, argumentation, and the education of gifted students. These three theoretical

areas provide a holistic teaching approach that supports students' reasoned thinking about controversial scientific issues, evaluation of multiple perspectives, and scientific decision-making processes (Erduran et al., 2004; Sadler, 2004; Zeidler et al., 2011).

The socioscientific issues teaching approach argues that scientific knowledge cannot be considered independently of its social, ethical, and political contexts and aims to engage students in active reasoning processes within these contexts (Sadler, 2004; Zeidler et al., 2011). Due to their inherent uncertainty, value conflicts, and multiple perspectives, socioscientific issues require students not only to learn scientific concepts but also to evaluate this knowledge alongside its societal consequences (Kolstø, 2001; Sadler & Zeidler, 2005). With these characteristics, socioscientific issues contribute to the development of a more critical and realistic understanding of the nature of science (Lederman, 2007; Yacoubian, 2015).

The Socioscientific Issues Teaching Framework developed by Friedrichsen et al. (2016) proposes that teaching such topics should holistically address context creation, scientific content, ethical and social dimensions, and students' reasoning processes. This framework enables students to position scientific knowledge not merely as content to be conveyed, but as a type of knowledge that is discussed and negotiated in social contexts (Friedrichsen et al., 2016; Sadler et al., 2007). Based on this theoretical framework, socioscientific dilemma cards were developed using Yacoubian's (2015) framework of Critical Thinking and Nature of Science Framework. These cards are designed to clearly highlight epistemological uncertainty, value-laden decision-making processes, and the evaluation of evidence in socioscientific contexts. Through structured dilemmas that encourage students to reason, compare alternative perspectives, and reflect on the nature and limitations of scientific knowledge, the aim is to support students' participation in informed and critical reasoning processes.

Argumentation is defined as a fundamental scientific practice that involves individuals defending their claims with evidence, evaluating alternative views, and reaching reasoned conclusions (Kuhn, 1991; Toulmin, 1958). Toulmin's argument model, with its structure consisting of claim, evidence, reason, supporting evidence, qualifier, and counterclaim components, is widely used in science education research to make students' thinking processes visible (Erduran et al., 2004; Sampson & Clark, 2008). Numerous empirical studies have demonstrated that argumentation-based learning environments support students' conceptual understanding, scientific reasoning, and critical thinking skills (Berland & Reiser, 2009; Osborne et al., 2004).

Argumentation processes conducted in sociological contexts enable students to reason not only based on scientific evidence but also by considering ethical, economic, and social values (Sadler & Zeidler, 2005; Zeidler & Nichols, 2009). In this respect, argumentation stands out as a thinking and learning practice suited to the multidimensional nature of socioscientific issues (Sadler, 2011).

The education of gifted students requires enriched, cognitively demanding, and flexible learning environments that support these students' high levels of curiosity, creativity, and problem solving potential (Renzulli, 2014; VanTassel-Baska, 2013). In this study, the teaching process was structured in line with the Triple Enrichment Model developed by Renzulli (2014). This model aims to deepen students' areas of interest, encourage higher-order thinking skills, and support them in producing original work (Renzulli, 2014; Subotnik et al., 2011).

The integration of socioscientific topics and argumentation-based activities with the Triple Enrichment Model provides a powerful learning environment that activates gifted students' cognitive depth, creativity, and task awareness (VanTassel-Baska, 2013; Zohar & Dori, 2003). This integrated structure supports students not only in producing knowledge but also in critically

questioning it and reconstructing it from different perspectives (Sadler, 2011; Subotnik et al., 2011).

Methodology

This research was conducted using a qualitative research approach with a case study design (Merriam, 2009; Yin, 2018). The case study provides a method suitable for the purpose of this research, as it allows for an in-depth examination of teaching practices conducted within a specific context (Yin, 2018).

The study group consists of gifted secondary school students enrolled at the Science and Art Centre. These Centres are supportive educational institutions affiliated with the Ministry of National Education in Turkey. They aim to identify the individual talents of gifted students continuing their formal education at an early age and to develop their scientific, artistic, and cognitive potential through enriched programmes (Ministry of National Education [MoNE], 2016). The implementation process lasted six weeks and consisted of four main activities, spanning a total of six class hours. The activities were structured in line with socioscientific subject-based teaching principles and designed to encourage students to engage in active discussion and argumentation (Friedrichsen et al., 2016). In the final activity, discussions were held on ethical, economic, and social dimensions using socioscientific dilemma cards based on Yacoubian's (2015) framework of critical thinking and the nature of science.

The activities carried out during the implementation process were structured to support students in gradually developing arguments within the context of socioscientific issues and are described in Table 1.

Table 1. Activities Implemented During the Instructional Process.

Activity	Description of the Activity	Pedagogical Purpose
Activity 1: Asteroid Modeling	Students created physical models to elicit their prior knowledge about the concept of asteroids.	To activate students' prior knowledge and foster affective engagement with the topic
Activity 2: Concept introduction of asteroid mining	The scientific and technological aspects of asteroid mining were explored.	To promote engagement with scientific content and awareness of diverse perspectives
Activity 3: Modeling of Metal Composition	The metals potentially found in asteroids and their possible uses were modeled.	To support the use of scientific evidence and reasoned thinking
Activity 4: Socioscientific Dilemma Cards	Discussions were conducted using dilemmas addressing ethical, economic, and societal dimensions.	To enable students to develop arguments by considering multiple perspectives

The data were examined through descriptive analysis, taking into account the structural characteristics of the arguments (Erduran et al., 2004).

Findings

In this study, the arguments developed by gifted students in the context of asteroid mining were analysed, taking into account their structural characteristics and levels of complexity. During the

analysis process, the students' arguments were classified into three levels: simple, advanced, and complex, using the Toulmin-based argumentation approach (Erduran et al., 2004; Toulmin, 1958).

The findings reveal that a significant proportion of students demonstrated reasoned thinking skills in a socioscientific context. However, these skills varied in terms of argumentation complexity. This classification of arguments into levels is consistent with the developmental progression proposed in the argumentation literature (Erduran et al., 2004; Kuhn, 1991). The distribution of argument types developed by students is presented in Table 2.

Table 2. Types of Arguments Developed by Students.

Argument Level	Frequency	General Characteristics of the Arguments
Simple Arguments	12	Arguments based on a single claim, containing limited justification, and primarily focusing on the potential benefits of asteroid mining
Advanced Arguments	11	Arguments incorporating scientific concepts and concrete examples, but including counterarguments to a limited extent
Complex Arguments	7	Arguments that integrate multiple perspectives, acknowledge potential limitations, and address ethical dimensions, demonstrating a high level of justification

Table 2 shows that students developed arguments most frequently at the basic and advanced levels. The fact that arguments at the basic level were mostly structured around a single claim and contained limited justification suggests that students initially approached the socioscientific topic superficially. This situation is consistent with previous studies showing that students initially evaluate socioscientific issues in a benefit-consequence-oriented manner (Sadler & Zeidler, 2005; Zeidler et al., 2009).

In advanced-level arguments, it was observed that students used scientific concepts more consciously and attempted to support their claims with specific examples and explanations. These findings parallel research showing that socioscientific issue-based learning environments support students' deeper engagement with scientific content (Evagorou & Osborne, 2013; Osborne et al., 2004).

Although complex-level arguments were developed by a more limited number of students, it was determined that these arguments addressed multiple perspectives, ethical concerns, and possible limitations together. Such arguments demonstrate that students incorporate not only scientific knowledge but also value-based reasoning into the process. This points to the potential of socioscientific issues to develop students' reasoning skills that take into account ethical and social dimensions (Sadler, 2011; Zeidler et al., 2011).

Discussion And Conclusion

The findings of this study reveal that socioscientific issue-based teaching meaningfully supports gifted students' argument development skills. The fact that a significant proportion of students moved from simple claim-based explanations to more structured and reasoned arguments confirm the role of socioscientific contexts in promoting scientific reasoning (Sadler, 2004; Zeidler et al.,

2009). This finding is consistent with studies arguing that socioscientific topics move students away from being passive recipients of information and towards active intellectual engagement (Aikenhead, 2006; Ratcliffe & Grace, 2003).

However, the relatively limited number of students developing arguments at a complex level indicates that some components of argumentation require more explicit and structured instruction. In particular, the limited use of higher-level argumentation elements such as refutation, the use of qualifying statements, and the systematic handling of counterarguments is a situation that has also been emphasised in previous argumentation studies (Erduran et al., 2004; Kuhn, 1991; Sampson & Clark, 2008).

From a pedagogical perspective, it can be said that socioscientific issue-based teaching has the potential to activate gifted students' multidimensional thinking skills. The use of a current and controversial topic such as asteroid mining has facilitated students' ability to relate scientific knowledge to ethical and social contexts. This aligns with studies arguing that socioscientific topics bridge learning with real-world problems (Sadler, 2011; Zeidler & Nichols, 2009).

Consequently, this study demonstrates that socioscientific issue-based instruction supports gifted students' argument development processes. Future research should examine how instructional designs that include longer-term applications, explicit argumentation instruction, and structured peer interaction affect students' ability to develop complex and multidimensional arguments (Mercer, 2000; Sampson & Clark, 2008).

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Connecting The Dots: Quassr Scores And S³R Profiles In Preservice Teachers' Socio-Scientific Scenarios

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This study is aimed to explore the relationship between preservice science teachers' (PSTs) socio-scientific reasoning (SSR) levels, evaluated through the Quantitative Assessment of Socio-scientific Reasoning (QuASSR), and their Socio-scientific Sustainability Reasoning (S³R) profiles through self-generated socio-scientific scenarios. A sample of eight PSTs created scenarios addressing a variety of complex socio-scientific issues. The research included qualitative analysis based on the S³R model framework to examine these scenarios. Quantitative results indicated that PSTs showed medium SSR levels, with notable strengths in the perspective-taking dimension and limitations in scepticism. However, scenarios produced by PSTs with lower inquiry scores demonstrated strong S³R profiles, excelling in components such as problematization and values. However, these lower inquiry participants showed deficiencies in the knowledge and governance dimensions compared to their higher inquiry. These findings illustrate a qualitative correlation between SSR and S³R profiles, accompanied by a quantitative discrepancy, particularly in the inquiry dimension. This discrepancy highlights the need for further exploration of measurement methodologies pertaining to the inquiry dimension within SSR assessments. The study contributes to the expanding literature on SSR by illuminating the complex interplay between quantitative and qualitative evaluations. It also offers crucial insights that may inform the development of effective pedagogical strategies aimed at enhancing the SSR skills of future science educators, thereby supporting their capacity to engage with contemporary societal issues critically and thoughtfully. Through this research, it is aimed to advance understanding of how different dimensions of reasoning can coexist and develop within preservice teacher education.

Keywords: Pre-Service Teacher Education, Qualitative Research, Science Education

Introduction

Socio-scientific issues (SSIs) are complex, controversial topics that require individuals to integrate scientific knowledge with social, ethical, and personal values to make informed decisions (Zeidler et al., 2005). SSR is usually viewed as a multidimensional construct, comprised of complexity, inquiry, perspective-taking and scepticism dimensions (Romine et al., 2017). Complexity reveals that SSIs cannot be addressed with singular and simple solutions due to the multi-layered structure of issues. Perspective-taking indicates that different stakeholders involved in SSI topics can develop different but contextually valid solution proposals in line with their individual priorities, beliefs, and prejudices. Inquiry emphasizes that SSIs involve numerous questions awaiting answers in both scientific and social contexts and therefore require a continuous process of research and debate. Scepticism requires careful selection of information sources related to these issues; it necessitates questioning whether sources are biased and whether the data presented is reliable (Sadler et al., 2007) Together, these dimensions indicate how well individuals can apply scientific understanding and reasoning within the context of SSIs while integrating relevant social and ethical considerations. It is especially important for preservice science teachers to develop strong SSR skills, because their reasoning practices will influence the framing, discussion, and negotiation of socio-scientific issues in future classrooms.

Developing socio-scientific reasoning (SSR) skills is crucial for citizens to effectively engage in contemporary societal challenges such as climate change, genetic engineering, and energy production (Sadler et al., 2007). Assessing PSTs' SSR through self-generated SSI scenarios

provides a valuable window into their understanding and application of these complex concepts (Ekborg et al., 2009). By creating their own scenarios, PSTs demonstrate their ability to identify and analyse key issues, consider different perspectives, and integrate scientific knowledge with ethical and social considerations.

The Quantitative Assessment of Socio-Scientific Reasoning (QuASSR) is a well-established instrument for measuring scientific reasoning skills (Romine et al., 2017). However, it primarily focuses on assessing SSR based on given cases. It is limited in its capacity to analyse discourse or other student-generated artifacts like SSI scenarios. In contrast, the Socio-scientific Sustainability Reasoning (S³R) model offers a structured rubric for examining reasoning across multiple dimensions in student-generated artifacts, including collectively produced texts and self-generated socio-scientific scenarios (Morin et al., 2014). Focusing on student-generated artifacts through qualitative analysis makes it possible to examine how individuals define socio-scientific problems, develop and justify arguments, draw on scientific and contextual knowledge, and deal with uncertainty within these issues. The S³R framework includes six interrelated components: problematization, interactions, knowledges, uncertainties and risks, values, and governance. Problematization focuses on recognizing the multidimensional structure inherent in the process of addressing an issue and understanding that the problem cannot be confined to a simple framework. Interactions emphasize awareness of the mutual relationships between components within dynamic systems and the complexity created by these relationships. Knowledges focus on how different sources of knowledge (experiential, social, local, etc.) are brought together and related to academic knowledge. Uncertainties and risks involve approaching claims of knowledge with caution, accepting that knowledge is contextual, and expressing scepticism at the epistemological level. Values focus on the explicit articulation of value-based attitudes and the justification of these attitudes. Governance addresses how regulatory mechanisms offer opportunities for citizen participation in the process of balancing different interests. S³R model provides a valuable rubric for assessing various levels of reasoning in different dimensions in student-generated artifacts (collective text on wikis) (Morin et al., 2014).

This study investigates the relationship between QuASSR-assessed SSR levels and S³R profiles in PSTs' scenario development. By analysing the scenarios developed by preservice teachers, we examined how their socio-scientific SSR skills, as measured by QuASSR, relate to their S³R profiles. This research will contribute to a deeper understanding of the multifaceted nature of SSR and provides valuable insights into developing practical pedagogical approaches that foster SSR skills in future science educators. Our research question is as follows:

What is the relationship between QuASSR-assessed SSR levels and S³R profiles in pre-service science teachers' socioscientific scenario development?

This study will contribute to a growing body of research on SSR by exploring the interplay between quantitative and qualitative assessments. By examining the relationship between QuASSR scores and S³R profiles, we can better understand the factors that contribute to effective SSR in future science educators.

Methods

The participants of the study consisted of 8 pre-service science teachers (PSTs) (1 male, 7 female). There were 12 participants at the beginning; however, 4 of them was removed from the study as their scenarios did not have characteristics of SSI. They did either not have any conflict or not include science. Within the scope of the 'Socio-scientific Issues in Science Teaching' elective course, quantitative data were obtained from the PSTs using the QUASSR (Quantitative Assessment of Socio-scientific Reasoning) scale, and qualitative data were obtained by asking

them to create a socio-scientific scenario. In the scope of the course, the nature of SSI were discussed in the first week. In the second week the PSTs were asked to fill in the QUASSR test. Then based on what they learned about the nature of SSI and the example scenarios they read in QUASSR test, they were asked to create their own scenarios. They were allowed to select any topic they were interested, either any topic they are experiencing or witnessing or any hypothetical topic they were expecting to be an issue in the future. Then, they were given time to make research to create their scenarios. The limited number of participants was suitable for the qualitative approach of this study, since the goal was to conduct a detailed examination centered on the reasoning patterns demonstrated through self-generated socio-scientific scenarios.

The QUASSR scale developed by Romine, Sadler, and Kinslow (2017) includes two socio-scientific cases (Hydraulic Fracking at Pavilion Wyoming and Branville Bay) with 11 two-stage questions each. These are related to the four sub-dimensions of socio-scientific reasoning (SSR): complexity (4 questions), inquiry (6 questions), perspective-taking (4 questions), and scepticism (6 questions). The Cronbach alpha reliability coefficient of the scale was calculated as 0.79 by Romine et al. (2017) and 0.82 by Irmak (2020), who adapted it into Turkish. The data from the QUASSR scale was analysed in line with the framework proposed by Romine et al. (2017). According to this framework, 0 represents low-level, 1 represents medium-level, and 2 represents high-level SSR. The average score for each SSR dimension for each PSTs were calculated using IBM SPSS software. Then, the PSTs were grouped as low-level and high-level SSR based on their QUASSR scores. PSTs having less than the mean score of the group were categorized as low-level SSR while the rest were categorized as high-level SSR group.

The scenarios were analysed according to the S³R (socio-scientific sustainability reasoning) model consisting of 6 components (problematization, interactions, knowledges, uncertainties and risks, values and governance) with the help of the rubric developed by Morin et al. (2014). Radar charts were drawn for S³R profiles of two SSR level groups. Radar charts were applied as a visual analytic to describe the relative distribution of S³R components between groups, and to compare the overall reasoning profiles. To ensure the trustworthiness of the study, different data collection methods were used, and the findings were interpreted together (triangulation). In addition, 35% of the scenarios created by the PSTs were analysed by both researchers, and the inter-coder reliability was calculated 0.83 (acceptable value) using the consensus/(agreement+disagreement) formula proposed by Miles and Huberman (1994).

Results

Table 1. SSR Scores of PSTs.

Participants	Complexity	Inquiry	Scepticism	Perspective-Taking	Total SSR
PST_1	1,25	1,17	0,33	1	0,9
PST_2	0,75	1,33	1,5	1	1,2
PST_3	1,5	0,83	1,67	1,25	1,3
PST_4	1,5	1,17	1,83	2	1,6
PST_5	0,5	1,67	0	1	0,8
PST_6	1,25	1,25	0,17	1,5	1
PST_7	1,5	1,5	1,33	1,5	1,25
PST_8	1,5	1,5	1	2	1,6
Mean	1,22	1,29	0,98	1,41	1,21

PSTs SSR scores ranged from 0.98 to 1.41 with a mean of 1.21 indicating medium SSR. The lowest mean score was found in scepticism dimension (M=0.98) and highest in perspective taking dimension (M=1.41), which is similar to the result of Irmak (2020). These findings suggest that PSTs generally demonstrate moderate level of SSR, which varies across different dimensions. SSR and S³R scores of the PSTs are provided in Table 1 and Table 2.

When PSTs scenarios were inspected, it was realized that their selected topics were about various topics: climate change (2), gene therapy (2), pharmacology, space research, genetically modified foods, and cosmetics. An example scenario (PST_4) about food capsules (GMF) can be given as follows:

“In the future, as humanity's resources decrease, scientists have developed a hunger-relieving capsule. This capsule provides the nutrients that a person needs, leading to a change in food production. Not feeling hungry all-day results in increased productivity and resource savings, which are among the advantages of this capsule.

However, just as any scientific development has advantages, it also has disadvantages. The effects of this capsule will be of the nature of a medicine, and like any medicine, they will have negative side effects that will affect people. Furthermore, this capsule may be addictive. Uncontrolled use will harm human health. Lastly, it reduces socialization because eating food is a social activity. People who use the capsule in just one sip will become more dependent on the easily accessible hunger-relieving capsule.”

PSTs' scenario texts were analysed based on S³R model. Their highest values were found in problematization dimension (M=2,63) while the lowest dimensions were knowledge (M=1) and uncertainties and risks (M=1,13).

Table 2. S³R Scores of PSTs.

Participants	Problematization	Interactions	Knowledges	Uncertainties and Risks	Values	Governance
PST_1	3	3	1	1	2	3
PST_2	2	2	1	1	2	3
PST_3	3	2	1	2	3	2
PST_4	4	2	1	1	3	1
PST_5	1	1	1	1	2	1
PST_6	2	1	1	1	2	1
PST_7	3	2	1	1	3	2
PST_8	3	3	1	1	3	3
Mean	2,63	2	1	1,13	2,5	2

Based on S³R scores radar charts were generated to illustrate the profiles of PSTs with different SSR levels. Each axis of the radar chart represents a component of the S³R framework: Problematization, Interactions, Knowledges, Uncertainties, Values, and Governance. The distance of each line from the centre indicates the level of each component within the S³R profile.

As in Figure 1, participants with higher SSR total scores (average of all dimensions together) tend to demonstrate stronger S³R capabilities across all dimensions. This suggests that a strong foundation in SSR is crucial for developing a holistic understanding of complex SSI.

In Figure 2, each radar chart represents the S³R profiles of the PSTs grouped by their performance on a specific dimension of the QuASSR instrument (Complexity, Perspective Taking, Inquiry, and Scepticism). When the radar charts created for four dimensions of SSR differently, some

inconsistencies with the one drawn based on SSR total scores are seen. While the overall trend was evident, notable inconsistencies emerged when examining the specific dimension of inquiry. Low-inquiry group's scenarios were assessed to be better in terms of most of the aspects of S³R except for interactions and knowledges.

Figure 1. S³R Profile of PSTs based on SSR Total Scores.

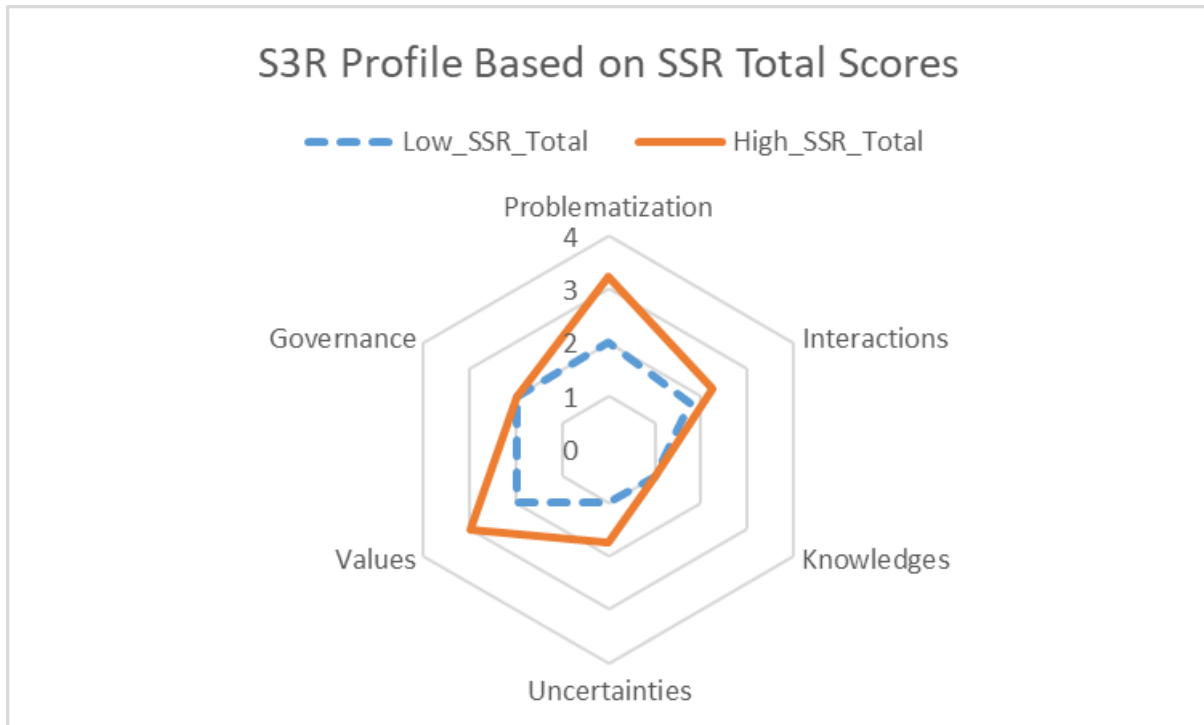
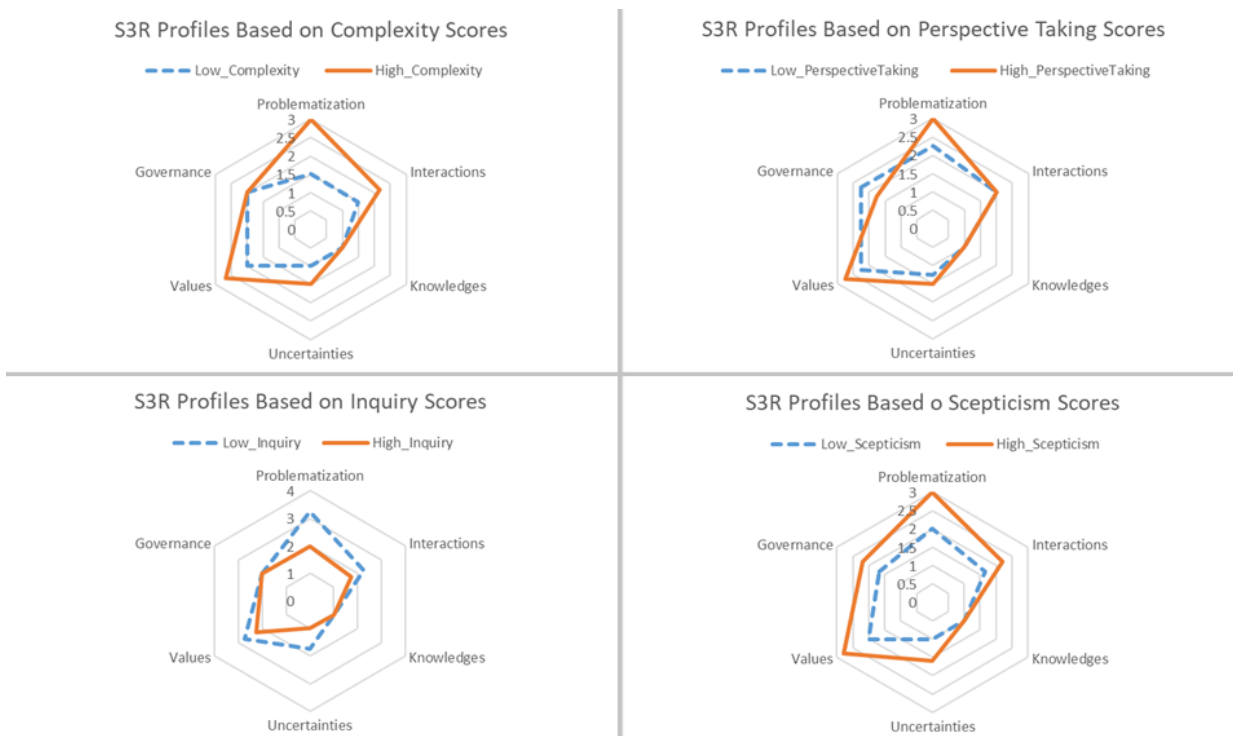


Figure 2. S³R Profile of PSTs based on Different Dimensions of SSR.



The inquiry dimension of SSR refers to understanding that there are many questions that need to be answered scientifically and socially in SSIs and that SSIs are open to continuous research in the scientific and social field, feeling the need to ask more questions and research more new information in the discussion of SSIs (Romine et al., 2017). Therefore, the radar charts indicated

that contrary to other SSR skills, inquiry is not an indicator of high-quality scenarios in terms of reasoning.

Discussion

This study investigated the relationship between QuASSR-assessed SSR levels and S³R profiles in preservice science teachers. While the findings suggest a positive correlation between higher QuASSR scores and stronger S³R profiles, the study also highlights the limitations of relying solely on quantitative measures like the QuASSR to fully capture the multifaceted nature of SSR. In particular, the results for the inquiry dimension suggest that quantitatively assessed SSR skills do not always align with the quality of reasoning evident in self-generated socio-scientific scenarios. Quantitative methods often fail to adequately capture the social, institutional, and relational contexts that shape values and reasoning (Morris, 1991). The QuASSR, for example, may not fully account for the diverse social and cultural backgrounds of the PSTs, which can significantly influence their perspectives on SSI. Conducting a qualified reasoning and interpretation process regarding SSI requires individuals to have a certain level of mastery over the relevant topics. In this context, selecting topics that individuals are familiar with in terms of knowledge and experience in studies addressing SSI will yield more reliable results (Tüzüngüç, Doğan & Han Tosunoğlu, 2021). However, in scenario-based and quantitative measurement tools such as QuASSR, differences in PSTs' prior knowledge of the scenario under consideration may cause the measured levels of SSR to be affected by scenario-specific knowledge gaps. This situation carries the risk that findings obtained with QuASSR may reflect PSTs' mastery of the scenario topic rather than their actual reasoning abilities, limiting the scale's use as a context independent assessment tool. Additionally, the focus on standardized questions may have overlooked the richness of qualitative data, such as personal experiences, interpretations, and emotional responses, which are crucial for understanding the complexities of SSR. Self-generated scenarios analysed through the S³R framework help make these implicit aspects of reasoning more apparent. As noted in the QuASSR validation process, inconsistencies across different scenarios highlight the potential for biases and limitations in quantitative assessments (Romine et al., 2017). Conversely, while qualitative methods can provide deeper insights into SSR, they may lack the generalizability and precision that quantitative approaches offer. A balanced integration of both methodologies could enhance the assessment of SSR, allowing for a more comprehensive understanding of this complex construct. In addition, these findings indicate that quantitative and qualitative approaches address different aspects of SSR.

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Unlocking Perspectives: Exploring Initial Design Principles Of Culture-Based Socio-Scientific Issues Training For Indonesian Pre-Service Biology Teachers

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In the last two decades, socio-scientific issues (SSIs) have been crucial in advancing scientific literacy. Students' socio-cultural backgrounds need to be considered in SSI-based education because cultural beliefs might influence their initial knowledge and guide their decision-making. SSIs require competent teachers, so it is important to introduce SSI-based education to pre-service biology teachers (PBTs), especially in Indonesia, which is known for its diverse subcultures and has limited research on SSIs. Currently, limited research examines how PBTs incorporate students' socio-cultural backgrounds when designing their CBSSIs classes. A deeper understanding of Indonesian lecturers and PBTs' perspectives is needed to understand how to develop a CBSSIs training programme for Indonesian PBTs to strengthen their skills in helping students navigate the complexity of science and culture. In developing the training programme, understanding the current landscape in teaching and learning SSIs and CBSSIs in the Indonesian context and the needs and aspirations of the CBSSIs training programme from lecturers' and PBTs' perspectives is needed. Semi-structured interviews were used to explore these perspectives. The results showed that teaching and learning SSIs is not done explicitly. Lecturers and PBTs shared their needs and aspirations for the training programme. Based on the results, five initial design principles (IDPs) were extracted to develop the training programme, which are (a) Understanding SSIs/CBSSIs, (b) Experiential Learning, (c) Collaboration and Reflection, (d) Accommodating Third Space, and (e) Theory and Practice. This work provides a basis for science educators on what principles to use when introducing CBSSIs to pre-service teachers.

Keywords: pre-service teacher education; teacher preparation; sociocultural perspectives; cultural diversity; socio-scientific issues

Introduction

In the last two decades, socio-scientific issues (SSIs) have been crucial in advancing scientific literacy. Ratcliffe and Grace (2003, p. 1) defined SSIs as “any issue which has a basis in science and has a potentially large impact on society”. In SSI-based education, students' socio-cultural backgrounds need to be considered (Zeidler & Kahn, 2014) because cultural beliefs might influence their initial knowledge and guide their decision-making (Wahono et al., 2021). However, Ladachart and Ladachart (2021) argue that teaching SSIs using cultural contexts, also known as Culture-Based Socio-Scientific Issues (CBSSIs), is mainly uncommon. Nelson and Braff (2020, p. 6) define culture as “a set of beliefs, practices, and symbols that are learned and shared”. Since teaching SSIs requires competent teachers (Subiantoro et al., 2021), and the success of navigating from everyday life to science classrooms and vice versa depends on the teachers (Aikenhead & Jegede, 1999), it is important to introduce SSI-based education to pre-service biology teachers (PBTs).

Currently, limited research, if any, examines how PBTs incorporate students' socio-cultural backgrounds when designing their CBSSIs classes; but doing so is important for fostering meaningful learning. Researchers have attempted to introduce SSIs to pre-service teachers (PSTs), such as Evagorou et al. (2014), focusing on how PSTs integrate content and pedagogical knowledge simultaneously; Espeja and Lagarón (2015) examined how PSTs conceptualise SSIs

using four categories: SSIs topics, controversy, uncertainty, and argument, and exploring PSTs' appreciation to teach SSIs; and Espeja and Couso (2020) emphasised that in preparing PSTs to teach SSIs, the lecturers should facilitate them to experience SSIs lessons themselves while also guiding them to design, implement and reflect on SSIs lessons. However, the efforts to introduce SSIs to PSTs in teacher training have not yet drawn on students' socio-cultural backgrounds despite the importance of providing meaningful and personally relevant science teaching. A deeper understanding of Indonesian lecturers and PBTs' perspectives is needed to understand how to develop a CBSSIs training programme for Indonesian PBTs to strengthen their skills in helping students navigate the complexity of science and culture. The research uses the Indonesian context because Indonesia is known for its diverse subcultures (Forshee, 2006). Also, there is still limited study of Indonesia's science education related to SSIs (Subiantoro et al., 2021). The research question is *What initial design principles can be used to develop a CBSSIs training programme for Indonesian PBTs?*

Methods

The study used a qualitative methodology. In answering the research question, a literature review and interviews were employed. Semi-structured online interviews were conducted with two Indonesian lecturers and three PBTs from one Indonesian public university. The selection criteria for the lecturers were those who had published a paper about SSIs, and the PBTs were based on their mixed abilities and coming from different parts of Indonesia. The consent forms were collected before the interviews. The interview protocols were adopted from the need analysis questions from McKenney and Reeves (2012) and questions from Subiantoro (2017) to explore the current landscape in teaching and learning SSIs and CBSSIs in the Indonesian context and ask lecturers and PBTs' needs and aspirations of the training programme. The interviews took around 1 hour each, mainly using the Indonesian language. However, some participants also spoke some English and Javanese (local language). After the five interviews were conducted, the interviews were transcribed for analysis. Then, the research participants were asked for approval to use the transcript. All of them agreed that the transcripts could be used in this study. The analysis was conducted in the original language spoken to maintain the nuance of the languages (Taber, 2018). The transcribed data were analysed using thematic analysis with the help of NVivo to extract initial design principles (IDPs) for a CBSSI-based training programme.

Results

The analysis reveals that the lecturers do not explicitly teach SSIs, as exemplified:

“I basically do not structure it or do not, in the quote, “explicitly” like... “Let’s prepare Biology education students to master SSI so that they can then implement the SSI learning model in schools”. No. It’s not explicitly structured the lesson like that” – Lecturer 2.

However, in the interview with the PBTs, PBT3 emphasised that they want to be explicitly taught SSIs. This preference can be incorporated as one of the IDPs, specifically focusing on *Understanding SSIs/CBSSIs*, as this is important in developing the training programme. It aligns with Anagün and Özden's (2010) statement that to be confident in teaching SSIs, understanding SSIs serves as a basis for introducing SSIs to PBTs, enabling them to teach CBSSIs.

In addition, Kolb's (1984) experiential learning theory highlights the importance of learning through experience. This theoretical perspective informed the training programme, equipping PBTs with authentic practice in designing and teaching CBSSIs. This idea also emerged from the interview, as the lecturers mentioned that PBTs should experience CBSSIs first-hand to help them understand the concept of SSIs/CBSSIs, suggesting that *Experiential learning* can be another IDP, where lecturers involve PBTs with direct experiences, as stated by Lecturer 1:

“We, as lecturers, apply SSI-based education in the class. Then, we told PBTs that what is being applied is SSI-based education. Or we can do it the conventional way: PBTs are told or asked to look for it [SSI-based education] and then discuss it in class. But I think I’m more interested in the first one. By implementing it ourselves, the PBTs will experience it [SSI-based education] themselves.” – Lecturer 1.

Furthermore, PBTs’ understanding of SSIs/CBSSIs can be promoted through collaboration, such as a co-design and co-teaching scheme (Foult et al., 2020; Huang & He, 2023), followed by a reflection session to enhance their understanding (Loughran, 2002). PBTs also explained that they need guidance in selecting and understanding appropriate issues for CBSSIs and analysing SSIs from diverse perspectives. PBTs also want their lecturers to support them in discussing and working collaboratively with peers in designing CBSSIs lesson plans, which leads to IDP *Collaboration and Reflection*, as PBT3 stated, “Maybe I only understand reproduction issues from my ethnicity. Maybe issues related to the circulatory or respiratory systems can be learned from other ethnicities.” – PBT3.

The statement above from PBT3 also implied that the training should leverage PBTs’ cultural background to introduce SSIs/CBSSIs. This also aligns with Lecturer 2’s concern that teachers need to address SSIs in culturally different settings when designing CBSSIs lessons. The third space concept, arising from the literature review, will accommodate how science, culture, and society intersect in CBSSIs. In teaching SSIs/CBSSIs, PBTs need to address students’ different cultural backgrounds (Tatham-Fashanu, 2023), facilitate the negotiation process between their everyday world and science class (Bhabha, 1990, 1994; Glasson et al., 2010), and navigate the tensions in SSI classrooms (Lee et al., 2020). These lead to the IDP of *Accommodating Third Space*.

Both lecturers and PBTs expressed that PBTs should be guided by lecturers in designing and implementing CBSSI lesson plans, which leads to IDP *Theory and Practice*, as stated by Lecturer 1, “I think it [the CBSSI lesson plans] would be more meaningful if implemented ... Hopefully, everything will be implemented from the concept to the implementation. But if not, at least until the implementation.” – Lecturer 1. It implies that, in addition to understanding the theory, PBTs need to practice what they have learned about teaching SSIs/CBSSIs to minimise the gap between theory and practice (Korthagen, 2010).

All five IDPs were extracted from the data analysis presented in Figure 1. These IDPs can be used to develop a CBSSIs training programme.

Figure 1. Initial Design Principles of CBSSIs Training Programme



Discussion and Conclusions

The study revealed lecturers' and PBTs' perspectives on the current teaching and learning of SSIs and CBSSIs and their needs and aspirations regarding developing the CBSSIs training programme. Enabling PBTs to understand SSIs and CBSSIs can be done through direct experiences as extracted to IDPs Understanding SSIs/CBSSIs and Experiential Learning. These findings align with research from Espeja and Couso (2020), who emphasised using the Experience-Design-Implement-Reflect pattern in preparing PSTs to teach SSIs. Espeja and Couso's (2020) work also aligns with the other IDPs: Collaboration and Reflection and Theory and Practice. PBTs collaborate with their peers in designing the CBSSIs lesson plan and reflect on their teaching skills. PBTs will also engage with theory and practice by implementing the CBSSIs lesson plan directly. This research found that Accommodating Third Space as an initial design principle is needed in developing the training. The third space theory provides a valuable framework to bridge students' background knowledge and science concepts in CBSSIs class. In the 'third space', students negotiate between their existing knowledge from everyday experiences and the novel concepts they encounter in science (Glasson et al., 2010). The third space can be used to explore and understand how science, culture, and society intersect to identify productive and culturally sensitive ways of negotiating science-society-culture in science education classrooms. In summary, five initial design principles (IDPs) were extracted in this study to develop the training programme, which are (a) Understanding SSIs/CBSSIs, (b) Experiential Learning, (c) Collaboration and Reflection, (d) Accommodating Third Space, and (e) Theory and Practice. This study provides a basis for science educators on what principles to use when introducing CBSSIs to pre-service teachers.

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Science Education And Communication: Innovative Methods To Promote Scientific Literacy

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The paper presents my Ph.D. research project, which aims to understand how to connect Science Communication (SC) and Science Education (SE) through edutainment, in order to develop Scientific Literacy (SL), which is necessary to cope with contemporary scientific and technological development (EC, 2015). To achieve this goal, we need innovative SE curricula that develop critical thinking (Akçay, 2018) and consider informal and non-formal educational contexts, such as SC on social media. The presented research is structured in two phases: an integrative review to identify the connecting elements of SC and SE through edutainment, and an educational research study aiming to exploit the educational benefits of SC in primary and middle schools. The results of the review allowed the creation of a teaching project based on active and cooperative learning methodologies, involving students as active users of SC and promoting SL. The research follows a phenomenological approach to explore students' and teachers' experiences and their meanings (Mortari, 2007) through different data collection methods. The final aim is to explore the benefits and challenges of SC in SE and to generate guidelines for STEM education to optimise and innovate the teaching experience.

Keywords: Science Education, Science Communication, Scientific Literacy

Introduction

This project addresses the need to enhance Scientific Literacy (SL) among 21st-century citizens (Serpa et al., 2021) in response to rapid scientific and technological development (EC, 2015). SL integrates knowledge and critical thinking (Ah-Namand & Osman, 2018), facilitates informed decision-making and responsible citizenship (EC, 2015) and develops through both formal setting with Science Education (SE) and non-formal setting with Science Communication (SC) (EC, 2020a). To be effective, SE should adhere to a multidisciplinary, reflective approach that fosters both disciplinary expertise and critical thinking (Akçay, 2018). As regards the SC, it raises awareness of STEM issues, fosters public trust in science (EREA, 2022), and conveys messages through accessible language, interaction and engagement, creating edutainment, an entertaining form of education (EC, 2020b). Moreover, digital technologies (which often play an essential role in conveying SC) facilitate interactive relationships between disseminators and audiences, promoting critical perspectives and responsible behaviour (López-Goñi & Sánchez-Angulo, 2018).

It is clear that SE and SC have areas of fruitful interaction, but despite their shared aims, their connection remains absent in educational practice (Everhart, 2009), due to a lack of research-based guidelines (Lewenstein & Baram-Tsabari, 2022). However, science communicators on social media contribute to public education, revealing a latent synergy between SE and SC. This dynamic became particularly evident during the COVID-19 pandemic, which underscored the need for education to address the infodemic through SC (WHO, 2020). As this occurs without explicit pedagogical frameworks, it can lead to an underestimation of the educational and formative potential of this tool, or its ineffective use.

This illustrates the urgency of innovation in STEM education, which requires a theoretical and practical bridge between SE and SC on social media through edutainment. This research aims to highlight its benefits and risks, offering insights, instruments and guidelines for STEM education,

shaped for teachers and shareable within different contexts, to innovate the teaching experience (Jorde & Dillon, 2012; Akkerman et al., 2021).

Research Design And Methods

Starting from the element that emerged from the initial literature review, the research is based on two research questions:

What are the most effective prompts offered by science communicators on social media, connected with edutainment, that it is possible to use to connect SC e SE positively?

How can be designed and realized teaching and learning project in the STEM area for different school levels (primary and middle school) which exploit the potential of SC in terms of engagement and use it as a stimulus to the development of SL?

The research design is structured into two phases to answer the two research questions. The first is an integrative review, which aims to identify the relevant theory and effective practices. The second is an educational research study, designed according to the results of the literature review, and implemented in primary and middle schools to foster SL development and assess its effectiveness.

Integrative Review

The first phase aimed to investigate, through a literature analysis conducted by an integrative review method, the relationships and implementation lines between SC on social media and SE through edutainment. The integrative review encourages complex phenomena investigation by connecting theoretical and empirical literature and focusing on the context, processes and subjective elements of the phenomenon, revealing different perspectives (Whittemore & Knafl, 2005). The databases consulted were JStore, Eric, Scopus, while the search strings contained the terms: “science education”, “science communication”, “edutainment” and “social media”. The search period covered twenty years, from January 2004 (the year Facebook appeared) to January 2024. Thirty-two papers were selected, and their analysis offered a theoretical background and practical-operational suggestions useful for the subsequent teaching project. They present teaching activities that link SC and SE through edutainment, employing different social media to propose a scientific mindset and content (Makarius, 2017) and facilitating learning (Swensen et al., 2014). Such tools are relevant for young people (Danielsson et al., 2023), as they share information and interests creating discussing networks (Bigelow & Kaminski, 2016). In the education context, they can promote peer-to-peer knowledge (Karahana & Roehrig, 2015), debate lesson-related content, and foster a process of knowledge co-construction (Dubovi & Tabak, 2020). This facilitates students' involvement both inside and outside the classroom, increases collaboration and creates a sense of community, leading to enthusiasm, motivation and engagement (Caratozzolo et al., 2022). Furthermore, they encourage content acquisition, creative thinking, problem-solving, and a reflective and searching perspective on scientific content (Bigelow & Kaminski, 2016). Such skills are needed as people increasingly search for information, including scientific information, online (Karahana & Roehrig, 2015). Individuals follow scientific content online for personal and educational interests (Rosenthal, 2018), but there is a risk that they assimilate information without critical thinking (Szu et al., 2017). Indeed, social media are nowadays, together with the school, among the educational contexts in which the scientific learning process takes place (Reid & Norris, 2016). In order to maximize the transformative potential presents in the relationship between SE and SC, it is necessary to design and promote innovative teaching methods that consciously integrate them. They should be linked with a specific effort aimed at educating young people to use all the tools at their disposal as a

stimulus to inform themselves and stimulate their curiosity, such as social media, which today represent a priority vehicle for the SC.

Teaching Project

The integrative review provided essential insights for the design of a teaching project that integrates SE and SC on social media through an edutainment approach. These findings served as the basis for the creation of two different teaching programs, which were adapted to the specific educational stages, one for fifth-grade primary and one for third-grade middle school students, and consisting of four/five sessions, lasting one to two hours each. The learning objective is to foster SL by promoting the development of scientific knowledge, as well as critical thinking and digital and information skills. To achieve this, the project employs Active Learning and Cooperative Learning methodologies. It emphasizes interactive activities that encourage students in active participation and engage them in both practice and reflective analysis moments. The project is structured into four phases, each of which is presented through practical activities related to the participants' personal experiences to facilitate understanding of the topics:

1. *Critical analysis of SC content*: students identify key indicators of effective SC (e.g. clarity, accuracy, engagement, etc.) reflecting alone and in pairs. This phase is useful for assessing the content reliability.
2. *Research on a scientific content*: after viewing a SC content video, in small groups, students define their topic and search sources and online information about it. During this phase, they assess the reliability and quality of the sources.
3. *Production of SC content*: students work in small groups to design communication plans and create videos using digital tools. The activities enhance and consolidate their learning.
4. *Sharing and discussing*: students present their content both in class and on dedicated social media platforms (created with appropriate ethical considerations of their use in an educational context), trying to be science communicators.

These steps are aimed at developing SC skills, from the search for information to the effective presentation of content, promoting teamwork and critical evaluation of sources and social media content. The goal is to shift students from passive to active consumers, enhancing their awareness of SC mechanisms through its implementation and fostering their role as student researchers and communicators, integrating scientific knowledge within a broader framework of knowledge and experience. Moreover, teaching programs were refined in collaboration with classroom teachers to ensure effective integration into existing curricula, addressing both content and pedagogical needs in different contexts. Meanwhile, an educational research study was conducted to assess the program's effectiveness, adopting a phenomenological approach to examine students' experiences and the meanings they attributed to them (Mortari, 2007).

Data Collection

The project was implemented in six schools located in different areas: the city centre, the suburbs and outside the town. Throughout the implementation phase (before, during and after), data were collected using various methods to capture different dimensions of the project.

Firstly, field notes and eye-guides completed during participant observation, together with pre-intervention teacher interviews, were used to understand the contexts and their specific needs, so that the educational project could be adapted accordingly. Pre- and post-intervention teacher interviews also provided insights into teachers' perspectives on the project, helping to identify its effectiveness and weaknesses from the viewpoint of key participants. Alongside the teachers' thoughts, students' opinions were gathered through self-assessment activities and audio

recordings of classroom discussions. Further data were collected to evaluate the project's two key objectives. The first aim focused on the development of critical abilities in evaluating sources and videos, and was examined through pre- and post-tasks, along with analysis, reflections and discussions on two videos, classroom audio recordings of dialogues and students' online searches. The second goal concerned the ability to produce a video, and was investigated using data on communication designs, student-created videos, and audio-recorded discussions.

Data Analysis

The data analysis is ongoing and follows a phenomenological approach, which requires conducting research in the field and observing phenomena as they occur, with the aim of understanding the lived experiences of participants (Mortari, 2007). The data are analysed using inductive content analysis (Elo & Kyngäs, 2008) and crystallisation technique (Ellingson, 2009).

Inductive content analysis is useful as often used to manage large volumes of textual data from diverse sources (Prasad, 2008), as in this research. It requires to transform the data into content-related labels and categories, creating a coding system (Elo & Kyngäs, 2008). Specifically, labels emerge directly from the text data becoming a coherent description of the studied phenomena (Elo & Kyngäs, 2008; White & Marsh, 2006). Different coding systems can be compared, allowing to create logical inferences between them. Moreover, the crystallisation technique facilitates the integration of these diverse forms of analysis into a coherent narrative. The aim is to gain a deep understanding of the phenomena by examining them from various perspectives using different types of data in order to reveal their nuances (Ellingson, 2009).

All the collected data cannot be analysed using the same method. Particularly, the videos produced by children require the development of a specific framework and an evaluation grid. This framework was developed through a literature review conducted using content analysis, which identified key elements to consider when producing SC videos for social media. Based on these elements, a supporting instructional tool was developed and proposed to the children, and an evaluation grid was derived from it and used to analyse the video data.

First Results

As seen, data collected allow to investigate different dimensions of the project, the results will describe these elements. Specifically, the educational research study investigates SC's educational potential by observing and analysing the setting, people interactions, their experiences, thoughts and learning objectives, allowing to investigate the effectiveness and areas for improvement of the project. Firstly, a preliminary context analysis was conducted using participant observation, eye guides and semi-structured interviews with teachers. Based on the data collected, the teaching project was refined according to the characteristics of each classroom, ensuring both research relevance and pedagogical applicability. For instance, the online information search activity was implemented in different ways based on dialogue with teachers regarding students' abilities. In particular, in some primary school classes, students could not find information online alone due to lack of digital skills, which is understandable given their age. For this reason, we decided to provide them with pre-selected online materials, including the necessary information for a reflection, such as source links, text and pictures. In these cases, the aim of the activity was not to find information online on their own, but rather to encourage critical reflection on the provided materials with the guidance of adults. Therefore, the program was designed and implemented in collaboration with teachers, recognising and respecting their professional expertise and class knowledge.

The remaining data are currently under analysis, with a particular focus on the perspectives of the main actors (students and teachers), as well as the two central themes. The first concerns the

development of critical thinking skills in the evaluation of online sources and videos. The second relates to students' ability to produce SC videos for social media, an activity that enables students to internalise the effective elements of such videos. Through this process, they become more aware of, and more critical of, the potential risks and benefits of online SC videos in their daily lives. Both abilities are necessary for developing students' SL, as they encourage critical thinking about scientific content and the development of an informed and conscious awareness of them in relation to everyday situations.

Conclusion

In conclusion, the project included an integrative review phase to identify the theoretical foundations and practical-operational insights present in the literature on the integration of SE and SC through edutainment on social media. The results of this review guided the design of an educational project aimed at promoting this integration in order to effectively fostering SE through an interactive and engaging approach that encourages students' critical thinking and SL, transforming them from passive to active users of SC. This process is part of an educational research study that examines the effectiveness of the teaching program by identifying both its strengths and limitations. To achieve this, various types of data were collected throughout the project's implementation, such as participants' perspectives and data on educational goals, that are currently being analysed.

Finally, the project aims to develop guidelines for STEM education innovation that align with technological advancements while bridging formal and informal learning environments and promoting informed decision-making and responsible citizenship among students. The research wants to contribute to the development of more effective and engaging STEM education strategies addressing the current social context.

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Understanding AI In Secondary School Education: How Technical Knowledge Affects Students' Technology-Critical Understanding

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Machine learning is widely used in society today. It is therefore crucial that children and young people develop insights into how machine learning works, as well as technology-critical skills to discuss and impact how AI and machine learning are used today. In this study, we present a first analysis to understand the interplay between technical and technology-critical skills, focusing on the reflections of lower secondary school students from interviews. Preliminary findings indicate that while some students developed an understanding of machine learning mechanisms, others struggled to relate machine learning to the real world. We discuss which relevant technical aspects of machine learning are needed for students to become able to develop technology-critical skills. Future research should explore how focusing on technical aspects in a deeper and more specific way affects students' technology-critical understanding.

Keywords: AI Literacy, Critical Thinking, Secondary Education

Introduction

In educational research there is an awareness of the importance of preparing students for a society that extensively uses AI. Curricula about AI and machine learning have been developed (Chiu, et al., 2022; Touretzky et al., 2023), and studies on societal impacts of AI have been conducted in relation to AI literacy (Lee & Kwon., 2024; Demir & Güraksın., 2022; Zambach, 2025). Those works are of importance for future generations' understanding of this domain in regard to taking a critical stance on the use and development of AI in society (Elicer et al., forthcoming).

The increased use and acknowledgement of machine learning and AI in society calls for more development and integration of curricula about AI and how it affects everyday life as well as teaching and learning (Yue et al., 2022; Smith et al., 2023). In that context, the purpose of this study is to explore secondary school students' understanding of machine learning. We present interview data as well as a work in progress analysis that maps the participating students' ability to critically understand the use and development of machine learning in society, based on their experiences with developing and discussing a machine learning model.

In this work-in-progress study we address the question:

How do lower secondary school students understand machine learning, and how do they reflect on technology-critical aspects of it based on their experiences in the classroom?

We investigate this using design methods and data consisting of six focus group interviews with students from 7th, 8th and 9th grade in a Danish school.

Case

This analysis is part of a research project based on developing a teaching sequence designed for lower secondary school in the context of biology as a school subject and using a scenario-didactic teaching approach (Fougt et al., 2022). The purpose of the research project is to examine students' understanding of machine learning models in the world, and to be able to critically evaluate the use of and responsibly develop such models in a STEM-context. In this context, technology-critical aspects refer to students' ability to critically reflect on topics such as ethical dilemmas and data usage in relation to society.

The course consists of a scenario where students act as employees in a fictional company that develops apps for health-tracking. In its current form, it has a duration of nine lectures of 45 minutes. By using Machine Learning for Kids (<https://machinelearningforkids.co.uk/>) to classify different images of food into different health related categories, the purpose is for students to learn the fundamental principles of machine learning models. After playing out different scenarios where the company enters a partnership with a fictional recruitment company, the students are to critically reflect on responsible usage of data and the influence on data-based algorithms in society. Afterwards the students discuss societal and ethical issues regarding the scenario. See an overview of the teaching lessons in the table below (Caeli et al., 2025).

Table 1. Overview of the teaching lessons.

Part 1: Preparation/Onboarding (3 x 45 minutes lessons)
Lesson 1: <i>Welcome</i>
Brief, phones, teams and welcome folder.
Lessons 2 and 3: <i>Onboarding</i>
The students work through an onboarding process as part of the newly started development department (an introduction and initial course in the program Machine Learning for Kids). The onboarding process is available as a step-by-step guide on a fictional intranet.
Part 2: Development (6 x 45 minutes lessons)
Lessons 4 and 5: <i>Developing the food app</i>
Video 1: The CEO of the fictional company explains the task. The students discuss how to categorize food into healthy and unhealthy and assign a score. Students are then told to categorize their images into healthy, medium and unhealthy. They work on their model in Machine Learning for Kids, i.e. categorize the images and train the model.
Lessons 6, 7 and 8: <i>Developing the health app</i>
Video 2: The CEO of the company announces the partnership with a fictional recruitment company. Students discuss and make notes on what data to collect about health, create a scoring system, test their solutions, create wireframes of the app, and see a dashboard for the recruitment company.
Lesson 9: <i>Discussing responsible development</i>
Department meeting: Discussion of the categorization, reaction to the deception of users (discussion on ethics and responsible development). Half of the teams must argue <i>for</i> and half must argue <i>against</i> profiling and selling data. Department meeting: The groups present pros and cons. They discuss whether their company should continue down this path and consider ethical principles for responsible development.

A pilot study was conducted in the spring of 2023 (see Caeli et al. 2024), the first full design cycle was conducted in April 2024, and the last iteration was conducted in November/December 2024.

Methods And Data

The following presents the methodological basis for interviews and the collected data.

Method

The research project was developed as a design study in collaboration between researchers and teachers. Data was collected through face-to-face qualitative focus group interviews, using semi-structured interview guides on specific themes. Open-ended questions elicited students' opinions, thoughts, and experiences to enable further course development and iterations (Creswell & Creswell, 2018).

The focus groups were interviewed prior to the development of the teaching sequence (August 2023) and follow-up interviews were conducted after the teaching sequence (December 2024, different students). The purpose of the interviews was to gain insight into the participating students' technical and technology-critical understanding before and after being taught a teaching sequence in machine learning in order to develop more relevant and appropriate teaching.

The preliminary interviews covered three themes: 1) Machine learning understanding, 2) Critical stance on machine learning and 3) Interaction between biology and machine learning. Follow-up interviews included questions on scenario didactics and teaching.

To answer the research question, we focused on: 1) Understanding machine learning and 2) Critical stance on machine learning in a biology context. In addition, we had a specific view on the relationship between technical skills and technology-critical skills in the classroom, based on experiences from our pilot. Additionally, we chose to use the term AI instead of machine learning because we expected students to be more familiar with this term. All interviews were coded in Nvivo.

Data

The data consists of interviews with students from lower secondary school as illustrated in the table below.

Name	Period	Type	No of participants	Level
Pre1, Pre2	Preliminary	Focus group interview	2 groups of 4 each	9 th grade
FO1, FO2, FO3, FO4	Follow-up	Focus group interview	4 groups of 4 each	2 classes from 7 th grade and 2 from 8 th grade

Findings

In the following we present our findings based on the two areas mentioned above.

Understanding Machine Learning

In the preliminary interviews, some of the participating students expressed that they lack, and would like to have, an understanding of how AI works, how it is used, and exactly what data is being collected by, for instance, social media. It also appeared that most of the participating students did not have any immediate thoughts about how machine learning works. However, one

student (Pre2), stated that AI can be used to create images, indicating an awareness of AI's capabilities.

From the interviews, some of the participating students seemed to have a broad understanding of the fact that the computer/machine is not intelligent in itself. A student expressed that it is humans who make the machine intelligent (FO1). Another student stated that it is not the machine that is intelligent, but that it is programmed and coded (FO3). In another interview, the students agreed that the machine is not intelligent like a human, partly because it does not know who the user of it is (FO4). From another interview a student expressed that it is the data that the computer uses that is intelligent, not the computer in itself (Pre2).

In one interview, a student presented an interesting opinion when answering yes to ChatGPT being intelligent because it is an artificial intelligence, putting emphasis on the word intelligence. Another student then emphasized that the intelligence is artificial and thus has a different understanding of why it is not intelligent (FO4).

In the follow-up interviews, we observed an overall understanding that the machine can learn (FO1-FO4), but, interestingly, not an overall understanding of how it works or what it actually is, which was one of the learning objectives in the project.

Critical Stance On Machine Learning

All students in Pre2 are aware that apps like TikTok, Netflix, and Instagram use data about them to target content. They seem to have an awareness and understanding that machine learning is used in many areas, although they seem to have a general understanding of AI.

In general, the students participating in the follow-up interviews are reflective about how organizations monitor data. One student reflected that the benefit of targeting ads lies with those who make money from them, but the student does not think it is okay that they know so much about the user (FO1). This attitude is echoed by another student who added that it is scary and weird that someone can know so much about you but also expressed that it is smart because it personalizes your experience (FO1). Another student agreed and is happy not to be shown useless videos (FO3) instead of (useful) user targeted content, and another said that machine learning is smart because you do not have to watch content you do not like (FO4).

Thus, a variation of what appears to be informed use seems to be present among the participating students, who take positions both for and against user targeted content (recommender systems) in, for example, social media. However, in another interview (FO3), the students expressed that they would like to know more about what AI does and how data is used by the company. In contrast to this, a student from another interview expressed that it is not necessary to learn about AI in their opinion (FO4).

Discussion

One observation was that while the students were taught how machine learning works, what data is, and critical aspects of data use, some students expressed they did not know what AI does and how data is used. As our teaching material focuses on the machine learning mechanism of image classification as part of a "health-app", perhaps the machine learning method related to the critical discussion about the use of data should be supplemented with deeper technical understanding, in this case of recommender systems. Recommender systems are another type of machine learning than classification methods, and they create the basis of the recommendations of social media. Likewise, the discussion was also affected by opinions on ChatGPT which is based on generative AI - yet another type of machine learning.

A practical implication of this finding is that when teaching machine learning, it is important to distinguish between these different types of machine learning methods and focus on the ones important for the project. Additionally, one could discuss the taxonomy of these in class for students to have a better chance of understanding different technical aspects of machine learning - and thus possibly also technology-critical aspects on a higher level.

Interestingly, we saw a similar pattern in a pilot study (Caeli et al., 2024), in which we had included block code programming for introducing deeper computational thinking (MIT App Inventor, <https://appinventor.mit.edu/>). This seemed to be time-consuming and distracting for students' technical understanding of machine learning, so we removed the block programming content in subsequent iterations.

Future research could consider exploring how deeper and more specific focus on technical aspects affects students' technology-critical understanding, i.e. the balance between the two aspects.

There are inherent limitations to this study, which is a work-in-progress study and thus focuses on a relatively narrow scope. Additionally, the study's reliance on a specific educational context in one school may not capture the full diversity of student experiences and understandings.

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