education sciences

MDPI

Article

Secondary School Students' Perceptions of Subjects in Integrated STEM Teaching

Anna Kellinghusen [1,*], Sandra Sprenger [1], Catharina Zieriacks [1], Anna Orschulik [1], Katrin Vorhölter [2] and Sandra Schulz [1]

[1] Faculty of Education, University of Hamburg, 20146 Hamburg, Germany; sandra.sprenger@uni-hamburg.de (S.S.); anna.orschulik@uni-hamburg.de (A.O.); sandra.schulz@uni-hamburg.de (S.S.)
[2] Faculty of Humanities and Education, TU Braunschweig, 38106 Braunschweig, Germany; katrin.vorhoelter@tu-braunschweig.de
* Correspondence: anna.kellinghusen@uni-hamburg.de

Abstract

This study examines students' perceptions of the subjects geography, mathematics, and computer science in integrated science, technology, engineering, and mathematics (STEM) lessons. Although the importance of an integrated approach in STEM education is emphasized, researchers are not clear about whether students perceive connections between the subjects on the one hand and subject-specific working methods and content in integrated lessons on the other. Data was collected in an integrated teaching unit on the sustainability of apples using an open-ended digital questionnaire in to two ninth grade classes in Hamburg, Germany (n = 38); this data was analyzed using qualitative content analysis. The results reveal that students perceive the subjects differently, but similarities can also be identified. While subject-specific content is perceived—such as the use of maps in geography, the calculation of volumes in mathematics, and Dijkstra's algorithm in computer science—methodological connections, such as calculating, analyzing diagrams, or solving problems, are anchored across disciplines. This suggests that the subject-specific contents are not lost in integrating lessons, and that connections among the subjects are, to a certain extent, promoted.

Keywords: STEM education; interdisciplinary education; education for sustainable development; problem solving; modeling; qualitative research; perceived subject

check for updates

Academic Editors: Sandra Nite, Niyazi Erdoğan, Jack F. Eichler and Federico Corni

Received: 20 May 2025
Revised: 13 June 2025
Accepted: 25 June 2025
Published: 28 June 2025

Citation: Kellinghusen, A., Sprenger, S., Zieriacks, C., Orschulik, A., Vorhölter, K., & Schulz, S. (2025). Secondary School Students' Perceptions of Subjects in Integrated STEM Teaching. *Education Sciences*, *15*(7), 821. https://doi.org/10.3390/educsci15070821

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Students are at the center of a dynamically changing world, since they are the future decision-makers who will have to deal with the pressing and complex challenges of the twenty-first century, and their skills and perspectives are crucial for the development of sustainable solutions to these complex challenges (Fensham, 2012). To meet these challenges, students need to bring knowledge and expertise from different areas of science, technology, engineering, and mathematics (STEM), understand them in their entirety, and develop innovative solutions beyond the classroom (Siller et al., 2024b). As STEM subjects are taught separately in many parts of Germany, it is necessary to break down the traditional thinking in subject disciplines and connect the knowledge and methods available in different subjects with each other, while encouraging connections among subjects (Bacon, 2018; Schulz & Pinkwart, 2016)—for example, the evaluation or modeling of data. Difficulty with linking subjects and methods can imply that identifying a subject is not clear to students or that it

even gets lost. According to Moore et al. (2014), just because connections among subjects are made in integrated lessons, there is no guarantee that students will recognize them or make the connections themselves. If students do not see the connections among subjects or are unable to make them themselves, much of the added value of integration may be lost to them (Moore et al., 2014). Another point emphasized by Shaughnessy (2013) in relation to mathematics in STEM is that the "M" must be made "transparent and explicit." It cannot be assumed that all students "see" the mathematics inherent in a particular problem (p. 324). This is also summarized by Margot and Kettler (2019) in their systematic review, stating that teachers were concerned that subject-specific depth would be lost and that subject-specific content could only be dealt with superficially in an integrated STEM curricula. Consequently, it is important that students are able to perceive the subject-specific topics and methods of each subject and that these are not lost during integration (Leung, 2020).

Therefore, the research interest of this paper is to identify whether and how students perceive the subjects of geography, mathematics, and computer science in integrated STEM education on the topic of education for sustainable development (ESD). This will enable the identification of differences between the didactic research in the literature on integrated STEM education and the actual experience in the classroom.

2. Theoretical Background

2.1. Integrated STEM Education and ESD

In recent years, there has been an increased focus on integrated approaches in STEM education, as these are believed to help improve student learning (Jong et al., 2020) while promoting the necessary skills, such as critical thinking or data analysis, that are needed in the twenty-first century (Bybee, 2010; Dare et al., 2022). The integration of STEM subjects is crucial not only for the acquisition of specific competences, but also for the development of knowledge needed to solve real and complex problems in an interdisciplinary manner (Siller et al., 2024a). By linking different subject perspectives in integrated STEM education, a holistic understanding of ESD from different subject perspectives can be promoted (Cordaro et al., 2025). Topics such as climate change or social justice can be addressed, using interdisciplinary learning methods, in many ways in integrated STEM education. This promotes overlaps between integrated STEM education and ESD, which can be made visible to students (Smith & Watson, 2019; Siller et al., 2024b). As a result, STEM education provides an opportunity to address issues formulated in an ESD context, thus contributing to the United Nations' (UN) Sustainable Development Goals (SDGs) (Siller et al., 2024b). This enables learners to make informed decisions and take an active part in creating a sustainable society (Siller et al., 2024b, 2025).

National frameworks support this integrated approach by formulating clear requirements for the integration of ESD into STEM education, such as the Framework for Global Development Education in Germany and the Next Generation Science Standards (NGSS) in the United States of America. The Framework for Global Development Education (Schreiber & Siege, 2016) makes it clear that the objectives of ESD include not only subject-specific perspectives, but also requirements for networked thinking, multiperspective perception, and complex action, which can be promoted in integrated teaching. This assertion is corroborated by the NGSS (NGSS Lead States, 2013), which stipulate that students should be capable of developing an integration of scientific concepts and practices across different subjects (also referred to as crosscutting concepts). For example, the topic "Earth and Human Activity" addresses the manner in which human activities affect the Earth and how Earth's processes affect humans, thereby anchoring the concept of sustainability in Earth and Space Science.

2.2. Geography, Mathematics, and Computer Science in Integrated STEM Teaching

Integrated STEM education makes it possible to combine the topics and methods of single subjects to solve the complex problems of the twenty-first century. The integration of these subjects leads to a better understanding of the concepts and improvements in students' skills, as these four areas support each other. In turn, this stimulates students' interest and gives meaning and relevance to their activities (Vasquez et al., 2013).

Despite their subject-specific definitions, there are a number of similarities among geography, mathematics, and computer science. The three subjects share several approaches to problem-solving that are not only independent of each other, but are also complementary, such as deductive reasoning in mathematics, inquiry in science, and computational thinking in technology (Moore et al., 2014). A pertinent illustration of a complex problem is climate change, which can be meaningfully addressed through the integration of STEM subjects (Oldakowski & Johnson, 2017). Beyond problem-solving, there are additional commonalities, such as data analysis (data practices), modeling and simulation practices, and systems thinking practices (Siller et al., 2024a; Weintrop et al., 2016).

In STEM education, geography can be categorized as physical geography and, thus, as a natural science due to its working methods and content (Oldakowski & Johnson, 2017). Geography is, therefore, categorized as a science subject. Geography is an inherently integrated discipline (Baerwald, 2010) that adopts a holistic perspective of real-world problems (Biddulph et al., 2020) by interrelating the perspectives of human and physical geography (Dorn et al., 2005; Murphy, 2014). The integrated nature of geography lends itself to interdisciplinary connections with numerous other subjects (Stacchiotti et al., 2019). For example, the subjects of mathematics and geography offer a good opportunity to link content in both subjects (Laudares et al., 2016); the analysis of geographical scientific problems frequently requires the utilization of mathematical competencies (Hrynevych et al., 2022; Oldakowski & Johnson, 2017).

Just and Siller (2022) emphasized that the role of mathematics in integrated STEM education is a foundation and has a universal language, as it facilitates the interpretation and application of complex results in different contexts. However, they also mention that mathematics in integrated STEM teaching is often an auxiliary science that remains in the background and is usually based on (more or less complex) mathematical models in the context of science, technology, and engineering. According to Beaubouef and McDowell (2008), in the context of computer science, mathematical knowledge is necessary for understanding the basic mathematical principles in computer science, such as logic, computer theory, networks, databases, and programming languages. A good mathematical background is also essential for the calculation and numerical analysis and analysis of algorithms.

In the literature, STEM is often primarily associated with science and mathematics, while the connection with engineering and technology is rarely addressed (Schulz & Pinkwart, 2015). Computer science can be found in engineering and technology and is a central discipline in STEM education, as it promotes the development of crucial skills such as computational thinking (CT). CT refers to the thought processes involved in solving a problem in a manner that the problem and its solution can be understood by computers or formulated using a computer language. In this manner, it is possible to use computers as an aid in solving problems (Wing, 2006). Thus, developing CT skills enables students to understand and analyze complex problems, as computer science concepts are increasingly part of the problem-solving process in STEM subjects (ibid.), such as understanding and applying Dijkstra's algorithm. However, in current STEM education, many teachers do not appear to integrate much more than the pure use of computers as a tool in the classroom,

although the importance of a basic education in computer science is undisputed (Schulz & Pinkwart, 2015).

2.3. Perceptions of Geography, Mathematics, and Computer Science

Students' perceptions of subjects play a central role in subject didactic research, as these perceptions can provide information regarding students' understanding of a subject and whether this understanding differs from that of subject academics and researchers (Lam & Lai, 2003). Over 30 years ago, Spangler (1992) indicated that students' understanding of a subject can be the key to understanding their actions and failures. In the context of STEM education, this may imply that the added value of integration could be lost if students do not recognize the connections between the methods and content of each subject, which are considered to be essential by subject scholarship (e.g., Bybee, 2010; Moore et al., 2014). It should be noted that students' perceptions are not wrong compared to science, but reveal students' learning experiences and provide clues for improving curriculum and instructional design (Lam & Lai, 2003). There are various terms used in the literature to describe students' perceptions regarding a subject, which are often used interchangeably. The most common ones are "perceptions", "attitudes", "beliefs" and "conceptions"(ibid., p. 200). As there is no agreement on the use of the different terms (ibid.), the authors have chosen to use the neutral term "perception" in this study to capture the manner in which students perceive different subjects in the classroom.

When students come to class, they have already experienced everyday ideas and learning opportunities outside of school regarding different subjects, which can influence their perception of a subject in class (Schulte & Knobelsdorf, 2007). As emphasized by Wong et al. (2002), motivation and performance can influence students' perceptions of a subject, with the classroom experience proving to be a significant factor. This assertion is further substantiated by a study conducted by Wong et al. (2002), which found that mathematics teachers mostly use closed-ended problem-solving tasks in the classroom with little variation in the approach employed by the method. This resulted in students having a closed perspective of mathematics—for example, they considered numbers and arithmetic to be the essence of mathematics. This perception is in alignment with the prevalent societal belief that mathematics is confined to arithmetic or "computation" (Spangler, 1992, p. 19).

A study by Wong et al. (2002) revealed another important finding: the use of diagrams to solve problems in mathematics lessons was not considered mathematics by the students in the study. In addition, there are "attitudes" among students that mathematics is relevant in a logically structured manner, focuses on problem solving and its applicability to real-world situations, and has an additive accumulation of rules and concepts (Grigutsch et al., 1997). In order to change the overall perception of a subject, it is recommended, for example, to select authentic and real-life situations for mathematics (Wong et al., 2002) and engaging content and activities for geography (Kitchen, 2013), both of which can be optimally implemented in an integrated STEM lesson.

There are different findings in the research and literature on the perception of geography as a subject at the secondary level from the students' perspective. A widespread and partially outdated understanding of geography lessons at school is often limited to memorizing river and city names, working with maps, and reading travelogs (Holt-Jensen, 2018). With regard to the perception of geography as a subject from the students' perspective, Lam and Lai (2003) found that students do not have a clear understanding of geography as a subject, but still consider it interesting and relevant. In addition, students associate the subject of geography with the study of space, maps, and the human–environment system. In a study by Hopwood (2007, pp. 457, 459), the topics "People and the environment" and "Education for sustainable development" were perceived by students as part of geography.

In Kitchen's study (Kitchen, 2013), students suggested that their perceptions focus on places and maps. In addition, Norman and Harrison (2004) not only addressed attitudes toward geography as a subject in their study, but also survey ideas and associations that students have with the subject. The terms associated with geography include media, such as maps and globes, earthquakes and volcanoes, map reading, activities in the travel and tourism industry, global events, as well as weather and environmental problems.

Furthermore, the perceptions of noncomputer scientists reveal that they tend to be passive and show little interest in expanding their skills (Schulte & Knobelsdorf, 2007). Many students who see themselves as less-skilled users feel trapped in their level of competence. For example, someone who has learned basic skills in Word might continue to see themselves as a less-skilled user with Word skills (ibid.). Therefore, one goal of computer science teaching should be to become aware of the complexity of computer science teaching (Beaubouef & McDowell, 2008). In a study by Hinterplattner (2023), students in the fifth grade were examined before they had computer science lessons at school. The results revealed that the students had a rather vague picture of what computer science is and what a computer scientist does. This requires changing a few of the ideas regarding computer science and encouraging students to develop problem-solving strategies, for example, by making the classroom a safe space for experiments and creative ideas (Vivian et al., 2020).

Despite the growing interest in integrated STEM education (English, 2016; Portillo-Blanco et al., 2024) and the different individual perceptions of the subjects geography, mathematics, and computer science, little is known in the international research field regarding students' perceptions of individual subjects in integrated STEM education. The aim of this study is to identify students' perceptions of geography, mathematics, and computer science in integrated STEM education, with a focus on ESD.

The following research questions are addressed in this study: (RQ1) To what extent do students perceive the subjects of geography, mathematics, and computer science in integrated lessons? (RQ2) What role do content/topic, methods, and media play in integrated lessons, and how are they perceived by students?

3. Description of the Project

In the context of the BMBF-funded project called "Nachhaltig handeln—MINT4all", which translates into English as "Sustainable action—STEM4all", an integrated teaching unit encompassing the subjects of geography, mathematics, and computer science was developed for seven lessons (with each lesson being of a duration of 90 min) on the topic of "Sustainable consumption and climate change—using apples as an example". The teaching unit was held outside the regular timetable and on two consecutive days. The controversial question posed to the students in the unit was whether an apple from overseas can be more sustainable than a German apple in terms of greenhouse gas emissions. In Germany, domestic apples are frequently marketed as more sustainable due to the comparatively shorter distances between production sites and retail locations when compared to apples from overseas. However, a closer examination of domestic apples reveals that their prolonged shelf life is often maintained through storage in CA (controlled atmosphere) storage, a process that necessitates significant energy expenditure. In order to address this key question, students employed a range of integrated teaching materials in class, with a few materials possessing a specialized focus.

The aim of the series of lessons was to empower students to evaluate apples in terms of their country of origin and to critically reflect on their own consumer behavior. To this end, the aspects of greenhouse gas emissions of apples from overseas were included in comparison to those of domestic apples. The skills and knowledge that the students obtain can also be transferred to comparable topics, such as tomato or strawberry cultivation.

4. Methods

4.1. Sample

The data collection took place at the beginning of December 2023 as part of the "Sustainable action—STEM4all" project. In order to investigate the research questions, students from two ninth grade classes at a secondary school in Hamburg were surveyed using an open and digital questionnaire (n = 45). The ninth grade (14/15-year-old students) level is particularly suitable, as it can provide pre-teaching perception with regard to the subsequent upper secondary school level and as a result of the geography, mathematics, and computer science lessons that have already taken place. Computer science was not a compulsory subject in Hamburg at this time; thus, 24 students had not yet had any computer science lessons at this point.

4.2. Data Collection

The questionnaire had an open response format in which the students explained the perceived content and methods presented on subject-integrating materials and their assignment to the subjects. The task was explained in the following manner: "Explain which methods and content were addressed in the task or tasks and assign them to the subjects geography, mathematics, and/or computer science (multiple assignment of subjects is possible). Give reasons for your decision."

In Hamburg, Germany, it is common for geography, mathematics, and computer science to be taught separately in year nine, with little or no connection between the subjects (Brinda et al., 2008; German Geographical Society, 2014; Kultusministerkonferenz, 2022). In this teaching unit, the subjects were combined. The subject-integrated materials, consisting of slides or worksheets, are interdisciplinary, but have a focus of one subject (see Table 1). The teaching materials are available in German at Vorhölter et al. (2025). In the first material, the students had the task of comparing the different apple-growing regions in terms of climate zones, climate data, and seasonal calendars (focus on geography—M1). Thereafter, they evaluated a pie chart that depicted the reasons for importing apples to Germany (focus not defined—M2). Since the evaluation of diagrams is used in all three subjects, the focus is not defined. In the third material, the students dealt with the transportation of apples from overseas to Hamburg, Germany. First, various transportation routes and means of transport were collected on a world map in plenary (focus on geography—M3). The fourth material asked the students to determine how many apples can be transported to Hamburg on a container ship, and different assumptions and mathematical models were explained in more detail (focus on mathematics—M4). Furthermore, in the fifth material, the students learned how an algorithm works (focus on computer science—M5). Then, in the sixth material, they applied the Dijkstra algorithm to determine and compare the different transportation routes with the lowest greenhouse gas emissions for apples from overseas and that of apples from the domestic apple-growing area to the supermarket (focus on computer science—M6). In the seventh material, the greenhouse gas emissions of the regional apple were calculated over a calendar year, and the results were entered into a coordinate system (focus on mathematics—M7). In the last material, the students evaluated a slide to answer the question of why greenhouse gas emissions per kWh from overseas, using South Africa as an example, were higher than those in Germany (focus not defined—M8).

Table 1. Subject focus of the lessons.

Material	Subject Focus	Contents of the Materials
M1	Geography	Comparing growing areas in terms of climate zones, climate diagrams, crop yields, and crop calendars
M2	Not defined	Evaluating pie chart and other information
M3	Geography	Determining transportation routes and means of transport on a map
M4	Mathematics	Modeling the greenhouse gas emissions of a container ship transporting apples from overseas to Hamburg
M5	Computer Science	Introducing algorithms
M6	Computer Science	Applying the Dijkstra algorithm
M7	Mathematics	Calculating greenhouse gas emissions from the storage of a local apple with linear calculations
M8	Not defined	Evaluate two pie charts for power generation

4.3. Data Analysis

The students' responses were evaluated using qualitative content analysis, in accordance with Kuckartz and Rädiker (2023), using the MAXQDA24 program. A category system was developed by two researchers (first and third authors) to describe the students' perceptions of the subjects and their rationale in integrated lessons. The categories were developed using a deductive–inductive approach. Deductive categories were derived from the educational standards relevant to the respective subjects—geography, mathematics, and computer science (Brinda et al., 2008; German Geographical Society, 2014; Kultusministerkonferenz, 2022)—through the application of construction and assignment rules. The educational standards are particularly well suited as literature references, as the teachers use them as a basis for their lesson design and, thus, have an influence on the students' perceptions of the respective subject. For example, the category Algorithm (Dijkstra) from computer science was derived from the content area of algorithms from the educational standards for computer science, the category Modeling from the process-related competence mathematical modeling of the educational standards for mathematics, and the category dealing with maps from the competence area Spatial Orientation with the content of map competence from the educational standards for geography.

Additionally, during the analysis, new categories were inductively developed based on the data, enabling the inclusion of emergent themes and insights not explicitly addressed in the standards. These include the category "Topics: Anthropogenic Climate Change & Transport" in mathematics and computer science. The standards indicate that mathematics and computer science require an application area, although this is not explicitly defined. Furthermore, one category identified was "Difficult & Informed" in computer science and another was "Geography often Provides the Context and Mathematics and Computer Science Provide the Method". All categories were revised and reviewed throughout the process.

Furthermore, consensus coding was employed to ensure that the coding was consistent (Kuckartz & Rädiker, 2023). Initially, each researcher independently coded the entire data

material, whereby the individuals agreed on the definition of the categories. In the event of discrepancies in the coding, the text passages were discussed and a consensus was reached; thereafter, the coding was adjusted, and, in certain cases, the category system was defined more precisely and applied retroactively to previously coded answers.

5. Results

5.1. Occurrence of Perceived Subjects in Integrated STEM Teaching (RQ1)

In integrated lessons, the perception of various subjects by students reveals significant distinctions across different educational materials. Figure 1 presents various materials, with a focus on the respective subject in integrated lessons, and relates these to the percentage of mentions of the respective subjects by the students.

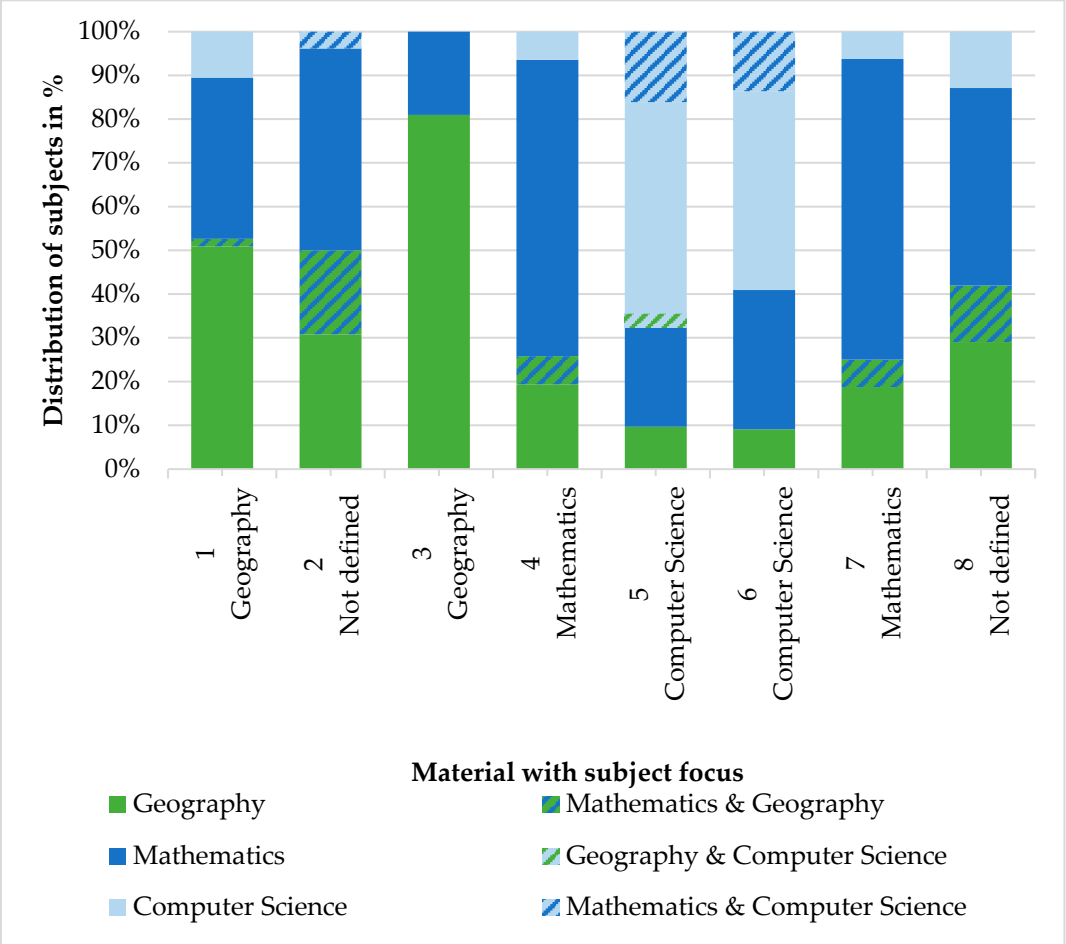


Figure 1. Percentage of students' perceptions of the materials in the subjects.

As originally assigned, the intended subject was also predominantly perceived by the students. For example, determining transportation routes and means of transport on a map (M3) is primarily geography, while modeling greenhouse gas emissions (M4) and the calculation of greenhouse gas emissions from the storage of a local apple with linear calculations (M7) are primarily mathematics.

It was evident that the subject of computer science was particularly perceived in the materials that focused on computer science. For example, students perceived computer science in introduction to algorithms (M5) and applying the Dijkstra algorithm (M6). In contrast, computer science was perceived less frequently in other materials. In addition, the subjects of mathematics and geography were perceived by students in all materials.

Moreover, it was evident that two subjects in one material tended to be perceived less by students than a single subject. The data revealed that the two most commonly perceived subjects in the materials were mathematics and geography, followed closely by mathematics and informatics. Specifically, the subjects of mathematics and geography prominently featured in the evaluation of a diagram (M2 and M8), while the combination of mathematics and computer science was prevalent in the context of introduction to algorithms (M5) and applying the Dijkstra algorithm (M6).

5.2. How Students Perceive the Subjects Geography, Mathematics, and Computer Science in Integrated STEM Teaching (RQ2)

The results reveal that the students had different reasons for why they perceived the subjects of mathematics and computer science in the different materials. An examination of the subject-integrating materials in the subject-specific content and methods of the sub-jects reveals that the duplication of categories and connections among the subjects was perceived (Table 2). The various results are listed below.

Table 2. Duplication and connection of topics/content, methods, and media between the perceived subjects.

Categories	Geography	Mathematics	Computer Science	Connected Subjects
Topics: Anthropogenic Climate Change & Transport	x	x	x	
Problem Solving		x	x	
Analyzing Diagrams	x			x
Calculation	x			x
Subject-Specific Content	x	x	x	
Subject-Specific (digital) Media	x	x	x	
Difficult & Informed			x	

5.2.1. Topics of All Subjects: Anthropogenic Climate Change and Transport

The topics of anthropogenic climate change and transportation were identified by the students as content that is addressed in the subjects of mathematics, computer science, and geography. Anthropogenic climate change includes aspects such as the greenhouse effect, greenhouse gas emissions, and climate change. For example, justifying the effects of greenhouse gases belongs to the subject of geography: "Geography must be applied be-cause the knowledge of the effects of greenhouse gases must be justified" (M7_student 10). More examples include "calculating greenhouse gas emissions from storage per month belongs to mathematics" (M7_student 4) or "finding the lowest CO_2 emissions in transportation (. . .) belongs to computer science" (M5_student 13).

The topic of transportation refers to various elements of the transport chain, such as the storage of apples or the choice of the means and routes of transport. Students perceived this content in all subjects. A student justified mathematics and informatics is used because "transportation routes with the least CO_2 emissions should be searched for or calculated. The algorithm was used for this. Therefore, the content was mainly associated with computer science and math" (M5_student 11). Another student assigned transportation to geography, as "means of transport and transport routes to name possible routes from South Africa to Hamburg" (M3_student 5).

5.2.2. Mathematics and Computer Science as Tools for Problem-Solving

To achieve a result, the subjects of mathematics and computer science serve as tools for students. Students utilized mathematical and computational methods to determine

sought-after values: "Mathematical methods and content were used to find the desired value" (M2_student 32) or, related to computer science, "applying the given method of the Dijkstra algorithm to arrive at the solution" (M5_student 36).

5.2.3. Analyzing Diagrams as an Interdisciplinary Discipline of Mathematics and Geography

The students' perceptions of the evaluation of diagrams were anchored in both mathematics and geography. This is evidenced by the statement, "It is mathematics and geography, as a pie chart had to be evaluated" (M8_student 32). Furthermore, the statement, "Since we worked with diagrams. . .," confirmed that the task involved both mathematics and geography (M8_student 38).

5.2.4. Calculation as Integral Components of Mathematics, Computer Science, and Geography

As is evident in the following quotations, calculation is a fundamental component of both mathematics and computer science: "Math is used by calculating data just like computer science" (M2_student 43) and "We also had to calculate the yield per hectare of the countries. I would assign this task to geography" (M1_student 38).

Another student emphasized that calculating the yield of apples per hectare is a geography exercise for him because he completed it in the spirit of geography. "I assign all tasks to the subject of geography, including task 3, although I did the mathematics, I did it in the spirit of geography science." He justified his statement by saying, "Just because I'm writing in a German subject doesn't mean that I'm in a German class. In my opinion, both the level of difficulty and the application of task 3 do not apply to mathematics" (M1_student 26).

5.2.5. Geography Often Provides the Context and Mathematics and Computer Science Provide the Method

The students' perceptions were that geography is often the content or context of the material and mathematics is the analysis. This was confirmed, for example, by student 7 on M8, who assigned energy production as a topic to geography and the analysis of a diagram to mathematics. Another student confirmed perceiving geography as the content: "It's a pie chart, but with geographical content. Therefore, the subjects are math and geography" (M8_student 13).

An additional illustration of geography serving as the context and mathematics as the method was observed in the material on modeling (M4). In this instance, student 2 allocated the transportation of apples on a container ship to geography and the calculation component to mathematics. This approach was also adopted in a similar manner with the Dijkstra algorithm material (M6). Student 31 assigned the transportation route of the apples and the greenhouse gas emissions to geography and the application of the algorithm to computer science.

5.2.6. Identifying Subject-Specific Content

Students perceive subject-specific topics and methods of the various subjects in integrated lessons.

According to the students' perceptions, the following are the concrete contents of geography in the present integrated lessons:

- The use of maps—for example, the reading of maps and the identification of specific locations (M1_students 5, 12, 13, 19, 25, 27, 33, 35, 36, 38, 43, and 44; M3_students 16, 22, and 40).
- Identifying climate zones (M1_students 12, 19, 20, 12, 27, 31, 37, and 38).

- Analyzing different areas where apples are grown (M1_students 18, 27, and 38).
- Analyzing climate diagrams with average temperatures and precipitation amounts (M1_students 1, 15, 22, 25, 32, 33, 36, and 38).
- Generating electricity (M5_students 7, 10, 14, 32, and 40).
- Cultivation of apples (M1_students 11, 20, and 31; M10_students 29 and 31).

According to the students' perceptions, the following are the concrete contents of mathematics in the present integrated lessons:

- Converting units (M4_students 2, 15, 19, 35, 37, and 19).
- Volume measurement (M4_students 7, 10, 19, 24, 33, and 43).
- Calculating percentages (M8_students 4 and 34).
- Calculating with formulae and equations (M1_students 25; M4_students 24 and 36; M7_students 34 and 36; M8_student 29).
- Creating functions (M7_students 8, 10, 11, 16, 18, 20, 31, 33, 35, and 39; M10_students 29 and 31)
- Finding the shortest path (M5_students 7, 11, and 24)
- Modeling (M4_students 1, 7, 36, 40, and 43)

It is the contention of the students that the following are the concrete contents of computer science in the present integrated lessons:

- Application of the (Dijkstra) algorithm (M5_students 7, 36, 38, and 39; M6_student 19).
- Determination of the shortest path (M5_students 7, 11, 19, and 20).

5.2.7. (Digital) Media Assigned to Specific Subjects

The perceptions of subjects among students indicate that certain media can be specifically attributed to particular subjects. In this context, the use of atlases, maps, and climate diagrams plays a central role in geography. In contrast, calculators and the digital program GeoGebra are significant for mathematics and computer science: "GeoGebra from the mathematics class" (M7_student 24) and "using GeoGebra [is] also computer science" (M7_student 7). In contrast, the evaluation of tables was perceived as an interdisciplinary method. The following statement is an example of the attribution to geography: "In order to complete the content of the task sheets, we had to work with climate diagrams, tables, and climate maps from the atlas" (M1_student 38).

5.2.8. Computer Science Is Perceived as Difficult and Students Feel Uninformed

A distinctive feature of computer science that is not present in other fields is the evaluation of tasks. Students indicated that they find computer science challenging and that they lack an understanding of the subject, which led to this perception. As one student stated, "Computer science, because I have no idea about it" (M5_student 16). Another student said, "I am not participating in the subject of Informatics, as I do not have the necessary skills" (M1_student 26).

6. Discussion

The findings of this study highlight that students perceive individual subjects in integrated lessons in a distinct manner. It is evident that the results of this study establish connections and distinctions with the perceptions of both the current state of research on individual subjects and scientific research on the role of subjects in integrated STEM lessons.

A key finding of this study is that the analysis of diagrams is perceived by students as a link between mathematics and geography. In Wong et al.'s (2002) study, a few students contended that the analysis of diagrams does not constitute a component of mathematics, as they perceive it as a futile exercise. However, the literature confirms that analyzing data,

including evaluating graphs, is a common feature of all STEM subjects, including computer science (Weintrop et al., 2016; Siller et al., 2024a); however, this was not perceived by the students in the current study when evaluating graphs. The prevailing tendency was to assign problem-solving to mathematics and computer science, despite the emphasis in the extant literature that such skills are characteristic of all STEM subjects (Moore et al., 2014).

In addition to working on connecting skills, students also identified the subject-specific content of each subject in the integrated lessons. It is important to maintain the centrality of a subject's disciplinary knowledge while promoting integration across subjects (Leung, 2020). To illustrate, in mathematics, modeling or volume calculation is regarded as concrete content. This is partially attributable to the lesson design, which anticipates complex mathematical competencies among students. It endeavors to present an authentic and comprehensive depiction of mathematics through real and authentic problems. Consequently, mathematics is not considered an auxiliary discipline in this article. This is consistent with the findings of the systematic analysis conducted by Just and Siller (2022), which indicates that mathematics occasionally functions as an auxiliary science in STEM subjects.

The results of this study also reveal that students use different media that are assigned to specific subjects—for example, atlases, climate diagrams, and maps for geography, calculators for mathematics, and the tool GeoGebra for mathematics and computer science. The association of media to subjects also corresponds with the results of Norman and Harrison (2004) and the results of Holt-Jensen (2018) and Beck et al. (2024), who associated, for example, maps or locations to geography or calculators to mathematics. However, Lam and Lai (2003) indicated that limiting the perception of the subject to media is not wrong, but does not capture the complex understanding of the subject by didacticians.

It is particularly striking that students have few concrete perceptions of computer science, which is not surprising given that many did not previously have any computer science lessons and, therefore, had no prior experience of the subject. This is also reflected in the low perception of computer science as a subject in materials that did not have a computer science focus. This assertion is further substantiated by a study conducted by Hinterplattner (2023), which revealed that numerous fifth-graders entered their inaugural computer science lesson with a lack of concrete understanding of the subject. A pervasive misconception that computer science is inherently challenging further exacerbates this uncertainty, a notion that is compounded by social prejudices, as articulated by Schulte and Knobelsdorf (2007). In order to combat such misconceptions, it is essential to organize computer science lessons in an application-oriented manner and not merely integrate the use of the computer as a tool—even though the important of basic computer science is indisputable (Schulz & Pinkwart, 2015). One example of promoting computer science is presented in an interdisciplinary approach by Schulz and Pinkwart (2016). This approach combines STEM subjects with the help of robots to improve competences in the fields of computer science, physics, biology, and chemistry. In this empirical study, it was shown that the process of working with robots is closely linked to experimentation and can be considered a scientific enquiry technique. Since results from the computer science education literature confirm the positive influence of robotics activities on intrinsic motivation, subject-related self-efficacy, and attitudes towards computer science (Kempf et al., 2020), the integration of robotics into other STEM subjects could have a positive influence on the aforementioned scales beyond computer science.

According to students' perceptions, the context of STEM lessons is often related to mathematics and geography, and the method is served by mathematics and informatics. A notable finding of Roberts et al.'s (2018) study was that context plays a pivotal role in students' engagement with STEM lessons, as it facilitates the resolution of real-world

problems. This finding is consistent with the literature on subject didactics, which suggests that geographical scientific problems can often be analyzed using mathematical skills and competences (Hrynevych et al., 2022; Oldakowski & Johnson, 2017).

However, there are two potential limitations regarding the results of this study. Firstly, as already described in the studies of Kitchen (2013) and Lam and Lai (2003), the personality of the teacher, the teaching methods, and topics/content on ESD can influence on the results. It is possible that, with a different teacher, students, teaching methods, or topics/content, different results could be obtained. Secondly, it can be assumed that transferring the results to other school curricula, who do not teach STEM subjects separately, will only be partially successful, since integrated teaching such as combined science courses is practiced to some extent in countries, for example, in Switzerland or the United States. Although the present research cannot eliminate this explanation, it appears useful to point out any issue that may conflict with these results. Despite these limitations, the results suggest that students perceive that the subjects are not lost in integrated STEM teaching, and that connections among the subjects are, to a certain extent, promoted. These findings support the further implementation of integrated STEM education at the secondary level, as certain students recognize the connections among subjects and perceive subject-specific content. Especially in terms of ESD, it is becoming increasingly important that students are able to make these connections between subjects in order to develop sustainable solutions and better understand complex interrelationships.

In terms of future research, the current findings could be extended by examining interviews with students in order to find out more about their detailed ideas on the subjects of geography, mathematics, and computer science in integrated teaching, as the closed answers on paper implied that no follow-up questions could be asked. In addition, it could be useful in the future to interview teachers in order to visualize their perception of the subjects of geography, mathematics, and computer science in integrated teaching, as they use terms and concepts related to integrated teaching in the planning and implementation of lessons and can, thus, indirectly transfer them to students.

7. Conclusions

The findings of this study highlight that students perceive subjects in integrated lessons differently, thereby exhibiting both content-related and methodical connections and duplications of categories among geography, mathematics, and computer science in integrated STEM lessons within the context of ESD. These connections and duplications of categories are partially consistent with existing research findings on the perception of subjects and science, but also exhibit contradictory aspects. This suggests that the subjects are not lost in integrating lessons and that the connections among the subjects are, to a certain extent, promoted. Integrated lessons have the potential to assist students not only in acquiring subject-specific knowledge, but also in developing knowledge of various subjects. This enables the complex challenges of the real world to be addressed in the classroom.

Furthermore, the connections among the subjects were perceived less frequently than the perception of individual subjects in the materials, thereby suggesting that not all students perceive all subjects in their integrated combination, but rather one subject in the materials. This may be due to the subject-centered timetable with which students are familiar. Moreover, the subject of computer science is particularly underrecognized, which is due to the fact that students had little or no previous experience with computer science. This suggests that the study of computer science at school should be promoted earlier and more strongly.

It is particularly noteworthy that students perceived a duplication of subject categories. Thematic areas encompassing all subjects include anthropogenic climate change and trans-

port, as well as methods of calculation. Students frequently associate problem-solving with mathematics and computer science, despite the literature asserting the necessity of incorporating all STEM subjects. Additionally, analyzing diagrams is often perceived as a process belonging to geography and mathematics, where the context is geography and the method is mathematics. Nevertheless, students also perceived subject-specific content, such as calculating volumes or modeling in mathematics, dealing with maps and climate zones in geography, and the (Dijkstra) algorithm and the shortest path in computer science.

Author Contributions: Conceptualization, A.K., S.S. (Sandra Sprenger) and K.V.; Methodology, A.K.; Validation, A.K. and C.Z.; Formal analysis, A.K. and C.Z.; Writing—original draft, A.K.; Writing—review & editing, A.K., S.S. (Sandra Sprenger), C.Z., A.O., K.V. and S.S. (Sandra Schulz); Supervision, S.S. (Sandra Sprenger), K.V. and S.S. (Sandra Schulz); Project administration, S.S. (Sandra Schulz). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Bundesministerium für Bildung und Forschung, grant number 16MF1017.

Institutional Review Board Statement: The study was approved by the Institutional Review Board of the Institut für Bildungsmonitoring und Qualitätsentwicklung (Institute for Educational Monitoring and Quality Development) (e514.101.5000-002/223,043, 23 November 2023).

Informed Consent Statement: Informed consent was obtained from all participants involved in this study. Participants were provided with detailed information about the purpose, procedures, and potential impacts of this research. Participation was voluntary, and participants had the right to withdraw at any time without any consequences.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

Bacon, K. (2018). *How do we coherently express an intention of curriculum integration in a re-devised primary school curriculum?* Paper commissioned by the NCCA.

Baerwald, T. J. (2010). Presidential address: Prospects for geography as an interdisciplinary discipline. *Annals of the Association of American Geographers*, *100*(3), 493–501. Available online: http://www.jstor.org/stable/40863545 (accessed on 23 June 2025). [CrossRef]

Beaubouef, T., & McDowell, P. (2008). Computer science: Student myths and misconceptions. *Journal of Computing Sciences in Colleges*, *23*(6), 43–48.

Beck, K. E., Shumway, J. F., Shehzad, U., Clarke-Midura, J., & Recker, M. (2024). Facilitating mathematics and computer science connections: A cross-curricular approach. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *12*(1), 85–98. [CrossRef]

Biddulph, M., Lambert, D., & Balderstone, D. (2020). *Learning to teach geography in the secondary school: A companion to school experience* (4th ed.). Routledge. [CrossRef]

Brinda, T., Fothe, M., Friedrich, S., Koerber, B., Puhlmann, H., Röhner, G., & Schulte, C. (2008). *Grundsätze und Standards für die Informatik in der Schule. Bildungsstandards Informatik für die Sekundarstufe I* [Principles and standards for computer science at school. Educational standards for computer science at lower secondary level]. Gesellschaft für Informatik e.V. [CrossRef]

Bybee, R. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35.

Cordaro, J. A., Murphy, C., & Redman, E. (2025). Bridging STEM education and sustainability: Insights from pennsylvania educators. *Education Sciences*, *15*(3), 282. [CrossRef]

Dare, E. A., Ellis, J. A., Rouleau, M., Roehrig, G., & Ring-Whalen, E. A. (2022, June 26–29). *Current practices in K-12 integrated STEM education: A comparison across science content areas and grade levels (fundamental)* [Conference session]. ASEE Annual Conference and Exposition, Conference Proceedings, Minneapolis, MN, USA. [CrossRef]

Dorn, R. I., Douglass, J., Ekiss, G. O., Trapido-lurie, B., Comeaux, M., Mings, R., Eden, R., Davis, C., Hinde, E., & Ramakrishna, B. (2005). Learning geography promotes learning math: Results and implications of Arizona's GeoMath grade K-8 program. *Journal of Geography*, *104*(4), 151–159. [CrossRef]

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, *3*, 3. [CrossRef]

Fensham, P. J. (2012). Preparing citizens for a complex world: The grand challenge of teaching socio-scientific issues in science education. In A. Zeyer, & R. Kyburz-Graber (Eds.), *Science/environment/health. Toward a renewed pedagogy for science education* (pp. 7–29). Springer.

German Geographical Society (Ed.). (2014). *Educational standards in geography for the intermediate school certificate with sample assignments* (3rd ed.). DGfG.

Grigutsch, S., Raatz, U., & Törner, G. (1997). Mathematische Weltbilder von Schülern Struktur, Entwicklung, Einflußfaktoren [Mathematical worldviews of students structure, development, influencing factors.]. *Journal für Mathematik-Didaktik*, *18*, 253–254. [CrossRef]

Hinterplattner, S. (2023). Students' perceptions of computer science and the role of gender. In J. Uhomoibhi (Ed.), *Computer supported education. CSEDU 2022. Communications in computer and information science* (Vol. 1817). Springer. [CrossRef]

Holt-Jensen, A. (2018). *Geography, history, and concepts* (5th ed.). SAGE.

Hopwood, N. (2007). Environmental education: Pupils' perspectives on classroom experience. *Environmental Education Research*, *13*(4), 453–465. [CrossRef]

Hrynevych, L. M., Khoruzha, L. L., Rudenko, N. M., & Proshkin, V. V. (2022). STEM education in the context of improving the science and mathematics literacy of pupils. *Journal of Physics: Conference Series*, *2288*, 012031. [CrossRef]

Jong, C., Priddie, C., Roberts, T., & Museus, S. D. (2020). Race-related factors in STEM: A review of research on educational experiences and outcomes for racial and ethnic minorities. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research in STEM education* (pp. 278–288). Routledge.

Just, J., & Siller, H.-S. (2022). The role of mathematics in STEM secondary classrooms: A systematic literature review. *Education Science*, *12*(9), 629. [CrossRef]

Kempf, F., Schulz, S., & Pinkwart, N. (2020, October 28–30). *Effects of robotics courses on student's attitude, motivation, self-concept and self-efficacy: An empirical study*. In Proceedings of the 15th Workshop on Primary and Secondary Computing Education (pp. 1–10), Virtual Event Germany. [CrossRef]

Kitchen, R. (2013). Student perceptions of geographical knowledge and the role of the teacher. *Geography*, *98*(3), 112–122. [CrossRef]

Kuckartz, U., & Rädiker, S. (2023). *Qualitative content analysis* (2nd ed.). SAGE.

Kultusministerkonferenz. (2022). *Bildungsstandards für das Fach Mathematik. Erster Schulabschluss (ESA) und Mittlerer Schulabschluss (MSA)* [Educational standards for the subject of mathematics. First school-leaving certificate (ESA) and intermediate school-leaving certificate (MSA)]. Sekretariat der Ständigen Konferenz der Kulturminister der Länder in der Bundesrepublik Deutschland.

Lam, C. C., & Lai, E. (2003). "What is Geography?" In the eyes of junior secondary students in Hong Kong. *International Research in Geographical and Environmental Education*, *12*(3), 199–218. [CrossRef]

Laudares, S., Laudares, J. B., & Libório, M. P. (2016). Geographic information systems used as a practical way of teaching mathematics. *Journal of Geographic Information System*, *8*, 608–617. [CrossRef]

Leung, A. (2020). Boundary crossing pedagogy in STEM education. *International Journal of STEM Education*, *7*, 15. [CrossRef]

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*, 2. [CrossRef]

Moore, T. J., Stohlmann, M. S., Wang, H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Research into practice* (pp. 35–60). Purdue University Press.

Murphy, A. B. (2014). Geographies crosscutting themes: Golden anniversary reflections on the 4 traditions of geography. *Journal of Geography*, *113*(5), 181–188. [CrossRef]

Next Generation Science Standards (NGSS) Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press. [CrossRef]

Norman, M., & Harrison, L. (2004). Year 9 students' perceptions of school geography. *Teaching Geography*, *29*(1), 11–15.

Oldakowski, R., & Johnson, A. (2017). Combining geography, math, and science to teach climate change and sea level rise. *Journal of Geography*, *117*(1), 17–28. [CrossRef]

Portillo-Blanco, A., Deprez, H., De Cock, M., Guisasola, J., & Zuza, K. (2024). A systematic literature review of integrated STEM education: Uncovering consensus and diversity in principles and characteristics. *Education Sciences*, *14*(9), 1028. [CrossRef]

Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., Craig Schroeder, D., Delaney, A., Putnam, L., & Cremeans, C. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experience. *International Journal of STEM Education*, *5*, 35. [CrossRef]

Schreiber, J.-R., & Siege, H. (Eds.). (2016). *Orientation framework for global development education in the context of education for sustainable development: A contribution to the Global Action Program "Education for Sustainable Development": Result of the joint project of the standing conference of the ministers of education and cultural affairs of the länder in the federal republic of Germany (KMK) and the*

federal ministry for economic cooperation and development (BMZ) [translation] 2004–2015 (2nd ed.). Cornelsen. Available online: http://d-nb.info/1083274139/04 (accessed on 20 April 2025).

Schulte, C., & Knobelsdorf, M. (2007, September 15–16). *Attitudes toward computer science-computing experiences as a starting point and barrier to computer science*. Third International Workshop on Computing Education Research (ICER '07) (pp. 27–38), Atlanta, GA, USA. [CrossRef]

Schulz, S., & Pinkwart, N. (2015, November 9–11). *Physical computing in STEM education*. Workshop in Primary and Secondary Computing Education (WiPSCE '15) (pp. 134–135), London, UK. [CrossRef]

Schulz, S., & Pinkwart, N. (2016, October 13–15). *Toward supporting scientific inquiry in computer science education*. 11th Workshop in Primary and Secondary Computing Education (WiPSCE '16) (pp. 45–53), Münster, Germany. [CrossRef]

Shaughnessy, M. (2013). By way of introduction: Mathematics in a STEM context. *Mathematics Teaching in the Middle School*, *18*(6), 324.

Siller, H.-S., Günster, S. M., & Geiger, V. (2024a). Mathematics as a central focus in STEM: Theoretical and practical insights from a special study program within pre-service (prospective) teacher education. In Y. Li, Z. Zeng, & N. Song (Eds.), *Disciplinary and interdisciplinary education in STEM. Advances in STEM education* (pp. 317–343). Springer. [CrossRef]

Siller, H.-S., Vorhölter, K., & Just, J. (2024b). Problem posing as a way of promoting individual mathematical thinking in STEM contexts—the case of climate change. *International Journal of Science and Mathematics Education*. [CrossRef]

Siller, H.-S., Vorhölter, K., Just, J., Orschulik, A., & Zieriacks, C. (2025, January 22–26). *Empirical differentiation of student competencies in ESD*. 27th ICMI Study Conference (pp. 503–510), Quezon City, Philippines.

Smith, C., & Watson, J. (2019). Does the rise of STEM education mean the demise of sustainability education? *Australian Journal of Environmental Education*, *35*(1), 1–11. [CrossRef]

Spangler, D. A. (1992). Assessing students' beliefs about mathematics. *Arithmetic Teaching*, *40*(3), 148–152. [CrossRef]

Stacchiotti, L., Acqua, A., Pennesi, D., Beccaceci, A., & Paris, E. (2019). WASTEBERG: A didactic activity about waste and sustainable use of georesources in relation to the Agenda 2030. *Rendiconti Online della Società Geologica Italiana*, *49*, 127–133. [CrossRef]

Vasquez, J., Comer, M., & Sneider, C. (2013). *STEM lesson essentials, grades 3-8: Integrating science, technology, engineering and mathematics*. Heinemann.

Vivian, R., Grover, S., & Falkner, K. (2020). Knowledge, skills, attitudes, and beliefs: Learning goals for introductory programming. In S. Grover (Ed.), *Computer Science in K-12: An A-to-Z Handbook on Teaching Programming*. Edfinity.

Vorhölter, K., Appel, C., Höttecke, D., Kellinghusen, A., Lohwasser, D., Monir, N., Orschulik, A., Oswald, L., Schuck, P., Schütte, M., Sprenger, S., Zieriacks, C., & Schulz, S. (2025, June 12). *Eine fächerintegrierende Unterrichtsreihe für den MINT-Unterricht aus dem Projekt "Nachhaltig handeln—MINT4all*. Zenodo. [File: FI_UE_Nachhaltigen Konsum-beispiel am Apfel]. [CrossRef]

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147. [CrossRef]

Wing, J. (2006). Computational thinking. *Communications of the Association for Computing Machinery*, *49*, 33–35. [CrossRef]

Wong, N.-Y., Marton, F., Wong, K.-M., & Lam, C. (2002). The lived space of mathematics learning. *The Journal of Mathematical Behavior*, *21*, 25–47. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.