education sciences

Article

Conceiving Socioscientific Issues in STEM Lessons from Science Education Research and Practice

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Abstract: This paper aims to elicit the different conceptions of Socioscientific Issues (SSI) in formal, non-tertiary STEM lessons. An examination of recent publications in the field of science education was conducted to elicit the most common conceptions of SSI as per the components of STEM lessons, namely: purpose, contents, teaching and learning strategies and assessment. As for purpose, the conceptions elicited have been organized in terms of contributing to citizenship goals, or to scientific competence. As for contents, it was found that SSI are related both to knowledge of science and knowledge about science and linked to skills such as argumentation. In terms of teaching and learning strategies, SSI are mainly associated with Inquiry-Based Learning; and with student engagement techniques such as dilemmas and group discussions. Lastly, performance assessment of student learning processes and results is typical when SSI are conceived as a method of assessment of STEM lessons. This conception sets up strong foundations for the design and evaluation of innovative SSI teaching. It shall also help to open new lines of research establishing connections among applications of SSI in different subjects, cultural contexts and educational systems.

Keywords: Socioscientific Issues; SSI; STEM education; educational innovation; non-tertiary education; formal education; STEAM education

Citation: Alcaraz-Dominguez, S.; Barajas, M. Conceiving Socioscientific Issues in STEM Lessons from Science Education Research and Practice. *Educ. Sci.* **2021**, *11*, 238. https://doi.org/10.3390/educsci11050238

Academic Editor: Ileana Maria Greca

Received: 8 April 2021
Accepted: 12 May 2021
Published: 17 May 2021

1. Introduction

In recent years, Science, Technology, Engineering and Mathematics (STEM) have become priority economic activities, especially in socio-economic and cultural settings where science, technology and innovation have a high value for progress and contribute to economic growth [1]. Consistently, educational systems worldwide are investing efforts to improve and optimize the learning of STEM subjects throughout all levels.

This effort can be seen, for example, in the amount of public funding that the European Union has allocated to promoting several innovations in formal STEM education. Some of these innovations are based on using digital learning resources and tools, for example, remote laboratories, [2], serious games or augmented reality [3]. Other projects innovate in the STEM teaching and learning processes, for instance by introducing Project-Based Learning or Inquiry-Based Learning as a way of making the learning experience more active and meaningful for students [4]. The shift from STEM to STEAM education also reflects the need for continuing innovation in this educational context, to reflect the growing integration of science and humanities in society in educational systems.

One of these innovations consists of introducing the so-called Socioscientific Issues (SSI). SSI have been defined as "complex and contentious social issues with substantial connections to science ideas and principles" [5]. Examples of current SSI are global warming, genetically modified organisms, sustainability, etc. SSI have been a strategy to engage students in learning STEM subjects, by conveying the growing importance that science and technology have in our society.

Such connection will allow students to see the purpose of learning STEM content, as well as empowering them as scientifically conscious and active citizens who will eventually participate in decision-making processes on scientific issues affecting society. As expressed in Romero-Ariza et al. [6]: "SSI are easily recognized by students as real-world scenarios related to contemporary issues, thus bringing a sense of authenticity and relevance to the science classroom" (p. 33).

As such, the SSI framework has been presented as a successor of other society inspired movements in science education such as the Science, Technology and Society (STS) movement, based on students' moral implication in the issue [7]. Therefore, the key elements inspiring the pedagogical application of SSI are that they (1) constitute practical applications of scientific knowledge to real life problems, (2) take place in the intersection of science and society, therefore supporting the idea that science must progress consistently and in accordance with the values and needs of the society in which it is developed and (3) are present in public discussion, often through the media [8].

In recent times, the pedagogical application of SSI has increased in both educational practice and teacher education [9–11]. More specifically, it is developing very rapidly in STEM lessons. A STEM lesson is a self-contained unit of learning that follows standard descriptions for Science, Technology, Engineering and Mathematics.

The pedagogical application of SSI in STEM lessons is especially common in non-tertiary education, which includes both compulsory and upper secondary education. In this specific educational level, a problem identified in the literature is the diversity of interpretations of the construct "SSI". For example, several works have elicited and characterized secondary school teachers' different interpretations of teaching SSI [12,13] and have warned about the problem of misconceptions between the intended purpose of SSI and its actual use [14–16]. Similarly, educational theorists and practitioners have been proposing applications of SSI in practice through design frameworks. These range from how to present a Socioscientific Issue [8] to more comprehensive frameworks that include a learning sequence as well as the role of the teacher and students [17]. Further, the definition of SSI compared to other science-in-society attempts to renew formal science education is still being discussed at a theoretical level [18].

This suggests that the pedagogical application of SSI is still open to interpretation both at a conceptual and practical level. This diversity is common given that SSI aims to improve science education and, as such, it is socially constructed. However, for SSI to be a stand-alone construct and a well-defined educational practice, some interpretations that define lines of action need to be established. This could contribute to understanding the phenomenon, especially in a moment where STEM education and SSI lessons raise more attention than current education.

In other words, SSI are a real-life phenomenon that are applied in an educational context, but there is a lack of agreement about how to do so. The increasing use of SSI has been interpreted in educational research as a need to elicit the existing conceptions of SSI in STEM lessons. Earlier contributions that explored this problem are available. For example, as a result of a Delphi Study, Irez et al. [19] propose an "SSI teaching and learning framework". The framework maps out SSI to already known concepts from this educational context, as learning outcomes, domains (cross-cutting themes), pedagogical strategies, features of the learning environment, nature of the instructional materials and sources and assessment. This effort suggests that there is a lack of consensus about one way of conceiving the usage of SSI in lessons, and this need has been addressed by expert evaluation.

Another approach to elicit the existing conceptions of SSI in STEM lessons is examining research and practice in science education. Science education is appropriate because out of all STEM subjects, experimental science is where the application of SSI has been most pervasive [5]. Research and practice publications are a suitable source of information because they address real education contexts. This is the case of Zeidler's [20] review, in which, by using the concept of "SSI as curriculum practice", he organizes SSI teaching in four themes: (1) the pedagogical application of classroom practice, (2) epistemological beliefs, (3) contexts for the nature of science and (4) development of morality. These categories can be interpreted as a scaffold to conceive the application of SSI in STEM education. For this reason, Zeidlers' review is an attempt to address the problem posed in this study.

With a similar motivation, the present study aims to look at this phenomenon from a different angle, known as "lesson components". Lesson components are well-established instruments to design and evaluate instruction, thus provide a solid structure to teaching and learning. Eliciting the different conceptions of SSI from this point of view is a unique approach that could provide strong foundations for SSI instruction.

There are several ways to define lesson components, some of which are more detailed or precise than others. In this paper we choose the following essential components of a lesson: (a) purpose (learning objectives of the lesson); (b) contents (body of knowledge, skills and attitudes that students interact with as part of a lesson); (c) teaching and learning methodologies (pedagogical techniques that are designed for learners to interact with the content and reach the learning objectives); (d) assessment criteria (which determine student performance standards). Here, these components are deployed as a framework of analysis of research publications.

Similar approaches been used in other innovations in science education, such as Inquiry-Based Learning (IBL). For example, Lederman et al. use a similar framework to conceive IBL, which can be interpreted as (a) a set of skills to be learned ("doing science like scientists do"), (b) as cognitive outcomes ("what students can do and know about inquiry") and (c) as a teaching approach to transmit science knowledge to students or help them acquire the knowledge [21]. This shows that our study is in line with a common function of educational research, which is to develop knowledge from practice.

However, to our knowledge the lesson components framework has not been used to elicit the conceptions of SSI in STEM lesson. In the case of SSI it can be especially useful as it can be considered a phenomenon that is not completely crystallized in practice and, consequently, in constant evolution.

Such contribution is relevant both for educational theory and practice. From educational theory, conceiving SSI is needed to define meaningful research lines, and thus, research problems associated with this important educational phenomenon. Through practice, conceiving SSI will eventually result in supporting the selection of more appropriate contents, methodologies and tools (needed) to approach STEM education in a meaningful and attractive way for students.

2. Materials and Methods

2.1. Research Design

Based on the problem identified, the present paper sets out to answer the following research question: (1) How do the conceptions of SSI (that are present in non-tertiary science education research and practice) relate to the lesson components?

To answer this question, research and practice in science education has been reviewed through a desk study of recent published papers. Desk studies constitute one type of secondary research to the extent that they involve analyzing existing data, as opposed to collecting primary data [22]. The present study, however, differs from other techniques based on collecting information from secondary sources, such as literature review. The goal of this study is to analyze and synthesize the conceptions that are intrinsically represented in published works, as opposed to presenting a state of the art of research in the field. For this reason, this specific methodology of review of research and practice is used, seeking to enlighten SSI in formal education through new ways of understanding.

Principles were applied to ensure validity and reliability, particularly the recommendations made by EPPI-Centre [23] for systematic reviews of research evidence. Thus, criteria for specifying which studies would be included in the review were determined: (1) Topic: literature must relate directly to the research question; (2) Type of publication: the information sources should be of an academic nature, where academic nature means that they aim to contribute towards knowledge development in this field; this includes journal articles, conference proceedings, books and book chapters; (3) Recency: all the sources should be from the last 15 years; (4) Geographical spread and cultural context: worldwide studies; (5) Reliability: findings upon which the literature is based are valid and reliable.

2.2. Research Procedure

The following objectives guided the research reported in this paper: (1) To collect science education publications reporting on the pedagogical application of SSI in the specific case of STEM lessons; (2) To select the publications in which the authors define, in an implicit or explicit way, the application of SSI to a lesson; (3) To organize the conceptions of SSI from the perspective of the four lesson components in formal education, namely: purpose, contents, teaching and learning methodologies and assessment, (4) Determine emerging categories that group the conceptions found in smaller units within the four components.

International databases such as (the) Web of Science and Scopus were used to access the publications. A total of thirty-three (33) papers have been reviewed. Additionally, six publications of different kinds have been part of this review, including publications in conference proceedings (2), books (1) and book chapters (3).

The study targeted publications concerned with SSI in STEM lessons in a non-tertiary, formal setting. Studies in science teacher education (normally pre-service) were also included if SSI are used as a way to improve the processes or results of STEM-related contents, as several of them are shared between non-tertiary education and pre-service education. Conversely, the review excludes papers reporting other pedagogical applications of SSI that are not an educational innovation.

The selected papers were analyzed in two cycles. In the first cycle, categories were identified. In the second cycle, a set of indicators emerged within those categories, thus adding another level of precision within the categories identified in the first cycle.

3. Results

The conceptions of SSI in STEM lessons were analyzed, synthesized and organized according to the four components of the lesson presented above.

Moreover, it was found that the papers reviewed might include conceptions of SSI in more than one lesson component. In this case, the paper is referenced in both components. The views are listed in Table 1 and summarized in the following sub-headings.

Table 1. Overview of the conceptions identified.

Lesson Component	Category	Indicator
Purpose	Citizenship	Citizenship education Political citizenship
	Key competences	Scientific literacy/competence
Contents	Scientific knowledge	Knowledge of science Knowledge about the Nature of Science
	Skills	Argumentation
Methodologies	Pedagogical strategies	Inquiry-Based Learning Discussions
	Engagement techniques	Dilemmas Case-based scenario
Assessment	Rubrics Questionnaires	Process Product

3.1. Component "Purpose of STEM Lessons"

The component purpose of STEM lessons is understood as what it is the lesson aims to achieve. The purposes can be expressed in different ways. The contributions of science education to an idea of citizenship and to developing key competences have emerged as the most common ways to express the purpose of STEM lessons in the papers reviewed.

At the level of citizenship, SSI are framed in the context of recent changes in society that aim to develop science and research activities in connection with society, which is promoted in several countries. In this view, students must be prepared to actively participate in decision-making processes that take place in a more open approach to science by getting involved in STEM-related common problems, which become SSI (e.g., climate change, genetically modified foods, etc.). This has been expressed as Citizenship Education (CE). Citizenship Education links the progress in science and technology to the need for students to be "critical-democratic citizens". Romero-Ariza et al. [6] use this approach as part of the three pillars informing their proposal for an Inquiry-Based Learning (IBL) methodology for SSI, known as Socioscientific Inquiry-Based Learning (SSIBL). This approach includes reflective learning, dialogic learning and democratic learning as pillars of the lesson. Without referring explicitly to Citizenship Education, Lundström, Sjöström, and Hasslöf [24] put forward a similar idea in their reference to SSI education as a continuum: "Cold-type SSI education is quite traditional science teaching with some socio-contextualization. It is characterized by monodisciplinarity and focus on content learning. Hot-type SSI, on the other hand, also emphasizes transdisciplinarity and political citizenship" (p. 21). The authors build on previous approaches to make these statements, such as Simonneaux [25].

The second application of SSI for the purposes of STEM lessons focuses on student development of key competences. In particular, Scientific Competence (SC) emerged, or its equivalent in other countries, namely scientific literacy. Scientific competence specifies what students must be able to do when it comes to dealing with natural and scientific phenomena. In this regard, it was found in the reviewed articles that SSI lessons are used as a way of contributing to student development of scientific literacy as it is defined at the time of speaking [26–28].

It was also found that SSI have been seen as an opportunity to discuss and redefine the meaning of scientific competence. Sadler et al. [29], for example, make the case that the increasing presence and role of SSI in society calls for a dedicated competence that they call Socioscientific Reasoning (SSR). As it was initially proposed, SSR included skills such as (1) considering complexity, (2) examining issues from different perspectives, (3) ongoing inquiry and (4) skepticism. Complexity is defined as the students' ability to deal with different factors as opposed to simple reasonings (such as cause and effect). Examining an issue from different perspectives involves recognizing and dealing with the different views that the people (or organizations) involved in an issue can have. Ongoing inquiry refers to the nature of SSI as a problem that is not very clearly defined but in constant investigation and development. Finally, skepticism is related to the students' ability to critically analyze the facts or information that are provided about an SSI considering the possible bias towards the sources of the information. These competences have been used as objectives for STEM lessons [30,31].

3.2. Component "Contents of STEM Lessons"

The component "contents of STEM lessons" is understood as the body of knowledge, skills and attitudes that students engage with as part of a lesson. The contents allow the objectives of the lesson to be achieved. The knowledge and skills are determined in the lesson itself; therefore, they can be very diverse. For example, the papers report experiences in which SSI are associated with different content, including content knowledge [32,33], scientific practices and attitudes expressed in different ways including the aforementioned Socioscientific Reasoning (SSR) [29]; informal reasoning [34]; moral sensitivity [35]; or what is referred to as "Communication skills" [36]. Sometimes these contents refer to the national curricula, therefore are nationally localized [37]. This means that even contents within STEM subjects can be formulated differently, also differing according to the levels within non-tertiary education.

To overcome this challenge, the papers were analyzed according to well-established constructs in the international educational research community, transcending the specificities of national curricula. The constructs that have guided our analysis of the conceptions of SSI can be divided between content knowledge and skills.

As per the knowledge, the conceptions of SSI found in the STEM lesson contents can be organized into two main types of scientific knowledge: (1) Knowledge of Science (KoS) and (2) Knowledge about the Nature of Science (KNoS). The first one includes the facts of products of the scientific activity (the laws and theories that constitute the knowledge body of science and technology), whereas KNoS describes the processes and resources that are involved in its development, i.e., how scientific activity is performed, and can be described as a meta-knowledge of science [38].

Regarding Knowledge of Science (KoS), some papers refer to SSI as specific curricular content. For example, Peel et al. report on a lesson belonging to the field on life sciences such as natural selection and antibiotic resistance [39]. In one of the studies presented by Albe et al., the SSI lesson covers the content of energy systems [40]. Another example, from Zeidler and Newton, reports on an SSI-mediated teaching and learning experience to teach about global climate change [30]. These papers provide an idea of the facts and products of science that are considered SSI worth knowing for students, to the extent that they constitute science and society concerns such as health or environmental issues. Other authors conceive SSI as scientific knowledge that is either unclear, in process of development, or unstable. This is often referred to as Science in the Making [26] and has been addressed by other publications that report on the application of SSI lessons such as Ekborg et al. [14]. Examples of these include nanotechnologies, stem cell research and bioengineering.

Regarding Knowledge about the Nature of Science (KNoS), SSI have mainly been conceived as "a means to discuss and learn about the connection between science and society" [37]. Zeidler et al. [7] refer to this as "epistemology of scientific knowledge as well as the processes/methods used to develop such knowledge" (p. 358). Examples from the review are Bencze et al. [18], who include SSI in the Science-in-Context (SinC) field, together with Science, Technology, Society and Environment relationships and "Socially-Acute Questions". These approaches aim to teach the conceptions, perspectives or skills that are associated with the non-desirable consequences of scientific or technological activities, for instance damaging the environment. Other examples are Eastwood et al., [41] and Khishfe [42].

A common way to operationalize these principles is Responsible Research and Innovation (RRI). RRI is a notion about the process of developing science and innovation from a societal point of view, and one that the European Union and other science and technologically developed regions, have been promoting for over a decade. RRI builds upon existing policies concerning the need to communicate and transfer results of research and innovation to citizens, and towards an approach where science and research activities consider the values, priorities and needs of those citizens [43]. One example of transmitting the principles of RRI in a STEM lesson is from Hadjichambis et al. The authors choose "The use of statins for cholesterol regulation" (which is controverted) to address the RRI aspects of "socially desirable, ethically acceptable and sustainable development" [44]. These are principles that guide the purposes of scientific activity, therefore belonging to KNoS.

In addition to scientific knowledge, another way to conceive content in SSI STEM lessons is skills. The most emphasized is argumentation [45–49]. Most papers locate argumentation as a process that students engage in while dealing with SSI. In this understanding, argumentation is a skill that students must be able to perform as part of STEM education, as a necessary skill in the process of sense-making and decision-making. These skills are important, according to the authors. For example, in their study about how to train primary school teachers to address SSI in their practice, Garrido and Couso include argumentation and critical thinking as Higher Order Thinking Skills (HOTS) [50]. Some of the publications conceiving SSI as a need to teach argumentation use or adapt the Toulmin argumentation principles, which includes claim, grounds, warrant, backing, rebuttal and qualification [51]. Another example of skills can be found in Tidemand and Nielsen's study about teachers' perceptions about using SSI [16]. The authors report that the skills that help to deal with SSI are underrepresented in the assessment items established in the curriculum in Denmark; these may include, for example, how to interpret the ethical implications of certain scientific progress.

3.3. Component "Methodologies of STEM Lessons"

The component methodologies of STEM lessons analyzes the conceptions of teaching and learning methodologies. This lesson component can be defined as what mediates between students, the teacher and the contents to be learnt. This allows studying the applications or adaptations of well-known, existing pedagogical strategies to the specific case of STEM lessons that include SSI.

Conceiving SSI to teach content is, as a methodology for STEM lessons, one of the most common, and it is therefore widely documented in the reviewed literature. Two categories emerged in this component, namely: pedagogical strategies and engagement techniques.

Pedagogical strategies are instruments that mediate between students and content. One that is frequently mentioned is Inquiry-Based Learning (IBL) [17,40]. This strategy is characterized by a process of collecting and analyzing data to answer a scientifically posed question, in this case, about a Socioscientific Issue. This technique has been attractive to the extent that it reproduces the scientific method, which is a way to create reliable knowledge based on evidence. Therefore, students' design or participation in IBL will help them to engage with the issue in a scientific way. As an adaptation of this strategy to SSI, the Socioscientific Issues Teaching and Learning model (SSI-TL) by Sadler et al. stands out [52] and constitutes a teaching and learning sequence in three main phases: (1) encounter focal issue, where students are presented with the issue; (2) engage with explicit teaching and learning activities; and (3) synthesize key ideas and practices. This model comes as a way to overcome earlier approaches that were used to design SSI curriculum units [53]. More recently, other authors have proposed revisions of this model [17].

Socio-Scientific Inquiry-Based Learning (SSIBL) is another manifestation of SSI in STEM lessons that follows the principles of Inquiry-Based Learning [6]. This pedagogical strategy is informed by three principles. First, authenticity, understood as framing scientific content in a scenario that is relevant to students. Authentic issues, according to the authors, affect students' lives and may be controversial. The second principle is mapping controversy. It refers to considering the opposing sides of an issue from different perspectives, such as risk versus benefit, or ethical principles. Third, SSIBL teaches students to act on the issue [54]. With a similar emphasis on decision-making, Saunders and Rennie propose a modification of the IBL strategy by adding an ethical component, in what they call "Model for Ethical Inquiry into Socioscientific Issues" [55].

In addition to IBL, another very common conception of SSI at the level of pedagogical techniques is group discussion. This technique can be defined as an evidence-based conversation that takes place where several views are exposed about a Socioscientific Issue [56]. When used as a pedagogical strategy, group discussion urges students to engage with the arguments for and against, as well as the different views, opinions and the evidence supporting them [56]. Group discussion is proposed with different pedagogical objectives in STEM lessons, including eliciting students' knowledge or position about the issue, presenting the different arguments about the issue, etc.

Student engagement techniques is the second category that emerged within this component. Compared to pedagogical strategies, engagement techniques do not constitute a model for students to learn or apply content. Instead, the goal of engagement techniques is to make students active participants in the learning activity. Those techniques start from the assumption that engagement comes from the inherently moral nature of SSI [7]. Two ways to engage students in the learning activity were found, namely the dilemma and case-based scenario.

The dilemma is a situation in which there is a need to decide between two alternatives, usually with neither of them being optimal [26,49]. According to Ratcliffe, the dilemma, as applied to SSI, focusses on the applications and implications of science [57]. The author conceives the following characteristics of the dilemma: (1) attractive (appeal to a reality that students can relate to; (2) authentic (deals with an issue that is connected to real life); (3) controversial (allows for different points of view). Even though some authors use dilemmas as the starting point of an SSI lesson [9], other authors do not constrain it to that specific purpose. This is the case of Alcaraz-Dominguez and Barajas [58], who report on the design and evaluation of SSI materials for secondary school teachers. In one of the papers, the term Socioscientific Issue and controversy or dilemma is used indistinctively [26]. The authors stress the need for dilemmas to be not only socially relevant scientific problems, but also to introduce conflicting interests by the parties involved.

Case-based scenarios are another way to engage students in learning about a Socioscientific Issue. The papers reviewed include efforts to create design guidelines for case-based STEM lessons. One example is Ekborg et al. [8]. In their proposal of "sociscientific cases", the authors propose a design and analysis framework based on six components: (1) starting point, (2) school science subject, (3) nature of scientific evidence, (4) social content, (5) use of scientific knowledge and (6) level of conflict of interest. Cases are also used to develop learning materials in the paper by Okada et al. [56]. These materials help students learn about SSI such as Genetically Modified Organisms, animal testing and others. Case-based scenario is a form of context-based teaching, which is a way to teach STEM in applied, relevant problems that students can identify with.

3.4. Component "Assessment of STEM Lessons"

Assessment is a way to gain feedback on students' learning process and outcomes. This component observes the conceptions of assessment in STEM lessons that deal with SSI. Assessment in formal education includes a variety of methods and compared to other educational contexts such as non-formal it is regulated in a more systematic way, due to the need to ensure that all students reach similar learning outcomes in each grade. Since SSI lessons are part of this system, different conceptions about assessment can be elicited from the papers reviewed in this study.

As a result of the analysis, it was found that most SSI lessons use performance assessment, mainly through rubrics. Rubrics may refer to the process and the results of student learning. In terms of process, rubrics are designed to gather information about student participation in the processes set for the lesson: participation, group work, data analysis, etc. For example, in material for teachers to address Genetically Modified Organisms (GMO) as a Socioscientific Issue, processes involving collecting evidence to decide or expressing a scientifically grounded argument are assessed through a dedicated rubric [56]. In terms of assessing the results of student learning, some of the materials developed by educational intervention projects use rubrics to evaluate a diversity of approaches, including student development of a product, or an essay [58].

Other tools, such as questionnaires, have also been developed to evaluate student learning in SSI lessons. For example, Romine et al. make use of the tool known as Quantitative Assessment of Socio-Scientific Reasoning (QuASSR) [59].

4. Discussion

This paper responds to the need to develop an understanding of how to include SSI in STEM lessons, by eliciting the current conceptions of SSI that can be found in science education research and practice. This is a common purpose of educational research and one that has been attempted before for SSI [12,13]. As a result of reviewing publications in the field of science education, and answering the research question posed, this study elicited different conceptions of SSI in relation to what has been defined as the lesson components. Lesson components, as sophisticated pieces of information, are one way to organize instruction, as per: purpose, contents, teaching and learning methodologies and assessment.

As per the first component, results show associations between SSI and two different ways to express the purpose of STEM lessons: (a) citizenship; and (b) scientific competence or scientific literacy, depending on the terminology used in each country. As for the first, the construct Citizen Education (CE) emerged, as well as the notion of political citizenship. Regarding the second, SSI are related to a reflection on the definition of scientific competence or literacy, which in the papers reviewed has been expressed in the construct of Socioscientific Reasoning (SSR).

Looking at the STEM lesson as a set of contents, both (a) knowledge and (b) skills, have been clearly identified in the conceptions of SSI. The scientific knowledge covered is expressed in terms of both Knowledge of Science (KoS) and Knowledge about the Nature of Science (KNoS). Regarding skills, its relation to argumentation has clearly emerged.

Considering the component teaching and learning methodologies of STEM lessons, the following categories have been identified: (a) pedagogical strategies and (b) engagement techniques. SSI are related to pedagogical techniques such as Inquiry-Based Learning and Group Discussion. The main student engagement techniques found were dilemmas and case-based scenarios.

Regarding the lesson component known as assessment, links were found between SSI and performance-based assessment, which is a way to collect information on students. Two categories emerged, namely (a) assessment of the process of learning and (b) assessment of the results of learning. Rubrics appear as tools to gather data about both, whereas questionnaires are used to measure the results of student learning.

As a result of the critical analysis of the papers, and beyond the classification of the conceptions of SSI according to the lesson components, it was found that the publications conceive SSI in more than one lesson component. For example, the SSI-TL model, which can be seen as a way to conceive SSI as a methodology for STEM lessons, also provides a conception of SSI in terms of contents, as expressed in the Next Generation Science Standards (NGSS) curriculum [45]. Another example is found in the dilemma-based SSI materials, which include content, methodologies and assessment [46,48]. These lessons start from the assumption that SSI contents can be embedded in the overall contents of the STEM curriculum. To teach SSI content, certain methodologies are proposed, as well as performance assessment techniques. The materials propose a continuum where contents, methodologies and assessment become more complex as both teachers and students become more experienced in SSI.

The results of this research have theoretical and practical implications. At a theoretical level, results are consistent with earlier research findings, for example some of the categories of Irez et al.'s Delphi study, namely "Learning outcomes" and "Pedagogical strategies" [19]. As for "Learning outcomes", our study reveals an emphasis in Knowledge of Science (KoS) and Knowledge of the Nature of Science (KNoS). Regarding KNoS, our study confirms that years after Zeidlers' review [20], teaching KNoS is still recognized as one of the key affordances of SSI in research and practice.

The classification from the Delphi study also includes "argumentation" as part of this category, which in our study emerged as "scientific argumentation", a key skill to develop in non-tertiary education. As for "pedagogical strategies", our research supports the prevalence of the association between SSI and Inquiry-Based Learning (IBL). On the contrary, the present review has not found clear evidence of other STEM teaching methodologies mentioned, such as cooperative learning. Similarly, no evidence has been discovered supporting the association between SSI and pedagogical techniques such as brainstorming, storytelling or drama, whereas the usage of dilemmas has been confirmed [19]. The differences observed between the present study and the Delphi study, which contribute to conceiving SSI in educational practice, may be due to the use of different research methods. Whereas the Delphi study is based on consensus among experts, the desk study is based on published documents.

At a methodological level, the study is useful to certify that the conception of SSI in STEM lessons is diverse and formulated by different levels of detail. For example, it was found that in lesson component (c) Methodologies, the definition of constructs is not sufficiently precise: sometimes the term SSI itself is used to describe strategies that are in fact pedagogical adaptations of SSI within the context of a lesson, such as dilemmas, or case-based scenarios. This is an area that could be investigated further and more systematically.

Still, this study provides outcomes of interest to the research on SSI. First, it provides a scaffold to evaluate SSI-mediated lessons in STEM formal education, which is new and based on a more established construct such as the lesson components. This classification constitutes a structure that could inspire research aiming to establish connections among practical applications of SSI in different subjects, cultural contexts and educational systems. Empirical studies about the use of SSI in practice could be compared, by creating connections between the conceptions that ground them. Second, the review performed also provides information about practical aspects of the pedagogical application of SSI which were not determined in the initial objectives of the study. For example, it has been observed that SSI are addressed in a wide range of levels and subjects across cultural contexts and local curricula, within non-tertiary education.

Beyond educational research, a key value of this study is its implications for educational practice. Eliciting the conceptions of SSI according to the lesson components framework could inform practitioners to better substantiate and promote the design of innovative SSI educational practices in formal STEM education. These practices would support different learning scenarios and learning strategies. An idea with a lot of potential in pedagogy and didactics is the close link that exists between the content and methodologies of a STEM lesson. In the review there is evidence of how certain methodologies are associated with specific content. For example, for certain content, an inquiry-based learning lesson is proposed around a dilemma, and student learning processes and products are evaluated through a rubric. These results are applicable in educational contexts beyond formal education. In fact, some of the publications reviewed report on SSI-mediated lessons in pre-service teacher education. Therefore, this model could also be used to design and/or evaluate SSI-mediated learning experiences in teacher education.

Finally, the findings may be of interest to other professionals who are not directly related to formal or non-formal education. In recent years, organizations such as research centers or universities have developed their outreach programs, where they implement strategies to involve students and citizens in their processes or raise awareness of their products. Becoming aware of the different ways to conceive SSI according to the lesson components could help these organizations to better design their resources and the corresponding student's engagement activities.

Author Contributions: The main author designed and carried out the research, under the supervision of the second author. Both authors contributed to all sections of the paper. Both authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the European Union Seventh Framework Programme, grant number 612269.

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

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