Characterisation of SSI-based instruction as an innovation in secondary education: a multiple case study in Spain

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Characterisation of SSI-based instruction as an innovation in secondary education: a multiple case study in Spain

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A mi madre, al meu pare.
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Abstract

One of the characteristics of knowledge societies is the increasingly important role of science and technology in our daily lives. In this context, there is a need in formal education to help students develop a scientific competence that allows them to exercise a responsible, active and conscious citizenship.

Socioscientific Issues (SSI)-based instruction appears like a suitable approach to meet this need. It is a teaching practice that contextualises student learning around contentious, often controversial social issues with connection to science, such as climate change, pandemics, or genetically modifying organisms. SSI-based instruction involves students in discussion, reasoning and decision-making.

This research aims to characterize the use of SSI-based instruction in secondary school, in the specific socio-educational context where SSI are only moderately supported in the curriculum and teacher education. This is a common situation, especially in the south of Europe, where the science curriculum has often been content-centred. In that sense, SSI-based instruction is seen as an educational innovation that science teachers carry out.

Two groups of teachers who practice SSI-based instruction were studied to describe this reality. Both groups of teachers do so in the context of their participation of an innovation project aiming to engage students in science by discussing SSI in science class. The analysis of SSI-based instruction has been approached through a three-dimensional framework covering the objectives, components, and resistances to this teaching practice.

This qualitative research based on multiple case study suggests that teachers see SSI-based instruction as a way to help students understand how scientific knowledge is applied in specific contexts and problems. Besides, it provides information about how teachers develop the components of SSI-based instruction in the specific case of a lesson, including learning methodologies, pedagogical techniques, and assessment of student learning. The study also characterises the generally positive attitude that teachers have towards this teaching practice.

Last, this research highlights resistances that are associated to school organisation and student skills, and provides information about how teachers overcome them.

On the basis of the results obtained, this study offers lines of action to support and promote SSI-based instruction, which can be applied in initial and continuing teacher education,
educational policy, curriculum developers and designers of educational materials. Future research is suggested, for example regarding the need for deeper understanding of teacher assessment of student learning in SSI-based instruction.

Keywords: Socioscientific Issues, SSI, SSI-based instruction, teaching practice, science education, educational innovation.
Resumen

Una de las características de la sociedad del conocimiento es la importancia creciente de la ciencia y la tecnología en nuestras vidas. En este contexto surge la necesidad de que la educación formal ayude a desarrollar una competencia científica que permita ejercer una ciudadanía responsable, activa y consciente.

La enseñanza basada en cuestiones sociocientíficas (CSC) emerge como una forma de satisfacer esta necesidad. Se trata de una práctica docente que contextualiza la enseñanza de las ciencias en cuestiones debatibles, que en muchas ocasiones son controvertidas y tienen un componente científico. El cambio climático, las pandemias, o los organismos modificados genéticamente se entienden como CSC. La enseñanza basada en cuestiones sociocientíficas implica al alumnado en debates, procesos de razonamiento, y fomenta la toma de decisiones.

Esta investigación pretende caracterizar el uso de la enseñanza basada en CSC en un contexto socioeducativo caracterizado por una atención moderada a estas cuestiones en el currículum y en la formación del profesorado. Esta es una situación común, especialmente en los países del sur de Europa, en los cuales la enseñanza de las ciencias ha sido y es mayoritariamente centrada en el contenido y las habilidades tradicionalmente "científicas". En este contexto, la enseñanza basada en CSC constituye una innovación educativa que el profesorado lleva a cabo.

Para describir esta realidad se estudiaron dos grupos de profesores de secundaria que practican la enseñanza basada en CSC. Ambos grupos desarrollan esta práctica en el contexto de un proyecto de innovación que pretende fomentar la implicación del alumnado en la ciencia mediante la discusión de CSC en el aula. Para el análisis, se utilizó un marco conceptual que comprende los objetivos, los componentes y las resistencias a esta práctica docente.

Esta investigación cualitativa, basada en un estudio de caso múltiple, sugiere que el profesorado percibe la enseñanza mediante cuestiones sociocientíficas como una manera de ayudar al alumnado a entender cómo el conocimiento científico se aplica en situaciones cotidianas y relacionadas con la sociedad. Además, el estudio aporta datos sobre cómo el profesorado desarrolla los componentes de la enseñanza basada en CSC en el caso concreto de una lección de clase, en términos de la secuencia de aprendizaje, estrategias pedagógicas y técnicas de evaluación del aprendizaje. Finalmente, el estudio caracteriza la actitud positiva
del profesorado hacia esta práctica docente, a la vez que apunta las resistencias con las cuales se encuentra y las estrategias que el profesorado emplea para lidiar con ellas. Estas se encuentran en la organización escolar y en las habilidades del alumnado, entre otros.

Con base en los resultados de este estudio, se aportan líneas de acción para apoyar y promover la enseñanza basada en CSC, las cuales se pueden aplicar en la formación inicial y permanente del profesorado, políticas educativas, desarrollo del currículo y diseño de materiales didácticos. Finalmente, se indican líneas de investigación futuras como por ejemplo la necesidad de entender mejor de qué manera el profesorado evalúa el aprendizaje del alumnado.

Palabras clave: cuestiones sociocientíficas, CSC, enseñanza basada en cuestiones sociocientíficas, práctica docente, enseñanza de las ciencias, innovación educativa.
Resum

Una de les característiques de la societat del coneixement és la importància creixent de la ciència i la tecnologia a les nostres vides. En aquest context sorgeix la necessitat que l'educació formal ajudi a desenvolupar una competència científica que permeti exercir una ciutadania responsable, activa i conscient.

L'ensenyament basat en qüestions sociocientífiques es presenta com una forma de satisfi la aquesta necessitat. Es tracta d'una pràctica docent que contextualitza l'ensenyament de les ciències en qüestions susceptibles de debat, que en moltes ocasions són controvertides, i que tenen un component científic. El canvi climàtic, les pandèmies o els organismes modificats genèticament són exemples de qüestions sociocientífiques. L'ensenyament basat en qüestions sociocientífiques implica l'alumnat en debats, fomenta el raonament, i implica la presa de decisions.

Aquesta investigació pretén caracteritzar l'ús de l'ensenyament basat en les qüestions sociocientífiques en un context socioeducatiu caracteritzat per una atenció moderada vers aquestes qüestions al currículum i a la formació del professorat. Aquesta és una situació comú, especialment als països del sud d'Europa, on l'ensenyament de les ciències ha estat i està majoritàriament centrat en l'ensenyament de continguts i habilitats "científiques". En aquest sentit, l'ensenyament basat en qüestions sociocientífiques esdevé una innovació educativa que el professorat du a terme.

Per tal d'entendre aquesta realitat, s'han estudiat dos grups de professors d'educació secundària en actiu que practiquen l'ensenyament basat en qüestions sociocientífiques. Ambdós grups de docents participen en un projecte d'innovació educativa que pretén implicar l'alumnat en la ciència a partir de la discussió de qüestions sociocientífiques a l'aula. Per a l'anàlisi, s'ha utilitzat un marc conceptual que contempla els objectius, els components i les resistències a aquesta pràctica docent.

Aquesta recerca qualitativa, basada en un estudi de cas múltiple, suggereix que el professorat entén l'ensenyament basat en qüestions sociocientífiques com a una manera d'ajudar l'alumnat a entendre com el coneixement científic s'aplica en situacions quotidians i relacionades amb la societat. A més, l'estudi aporta dades sobre com el professorat desenvolupa els components de l'ensenyament basat en qüestions sociocientífiques en el cas concret d'una lliçó, que inclou la seqüència d'aprenentatge, les estratègies pedagògiques i
l'avaluació. Finalment, l'estudi caracteritza l'actitud positiva del professorat vers aquesta pràctica docent, i analitza les resistències amb els quals es troba i les estratègies que utilitza el professorat per superar-les.

Tot basant-se en els resultats obtinguts, aquest estudi aporta línies d'acció que podrien contribuir a mantenir i promoure l'ensenyament basat en qüestions sociocientífiques, que es poden aplicar a la formació inicial i permanent del professorat, a la política educativa, al desenvolupament del currículum o al disseny de materials didàctics. Finalment, s'indiquen línies d'investigació futures, com per exemple la necessitat de comprendre millor de quina manera el professorat evalua l'aprenentatge de l'alumnat.

Paraules clau: qüestions sociocientífiques, ensenyament basat en qüestions sociocientífiques, pràctica docent, ensenyament de les ciències, innovació educativa.
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CHAPTER 1

INTRODUCTION AND OBJECTIVES
Chapter 1: Introduction and objectives

The present dissertation, entitled "Characterisation of SSI-based instruction as an innovation in secondary education: a multiple case study in Spain" is concerned with an increasingly frequent phenomenon in formal secondary education that demands to be understood, which is SSI-based instruction. This phenomenon can be described as a teaching practice where students learn science in the context of a Socioscientific issue, which is a contentious, social issue with links to science. This phenomenon has been approached in Educational research, but still demands to be understood in more depth in order not only to maintain it and promote it, but to deliver it to its full potential. On this basis, the first chapter of this dissertation constitutes an introduction that allows to understand why and how the research reported in it was developed.

To that goal, the first part of the chapter delimits this study within the broad field of educational research, by stating the problem. This step is necessary to understand the context, the theoretical groundings, and thus the motivation to develop a study on the phenomenon of SSI-based instruction. In this case, SSI-based instruction is presented as part of a socio-educational context where the concept of scientific competence is changing contribute to a responsible, conscious and active citizenship. These changes affect different aspects of secondary school and in particular, science instruction.

The second part of the chapter defines the research objectives. These are essential to keep the investigation focussed, and contribute to obtaining results that are relevant to the knowledge available on the subject.

The third section of this chapter provides the information necessary to understand the context in which the research was developed, which is an educational intervention aiming to increase citizen (in this case, student) engagement in science.

Finally, the last section of this chapter states the formal aspects of this dissertation, or how this document is organised. It includes a short description of the chapters, and other relevant data such as the use of language and abbreviations.
1. Problem statement

For a few decades now, a new teaching practice has taken place in formal education, known as Socioscientific Issues-based instruction. Socioscientific Issues (SSI) are defined as “open-ended, ill-structured problems which are typically contentious and subject to multiple perspectives and solutions” (Sadler & Zeidler, 2005; Zeidler, Sadler, Simmons, & Howes, 2005, p. 72). Different SSI come to public discussion as society evolves and develops. Examples of SSI from the last few years are related to evolution, nuclear energy, and reproduction (Borgerding & Dagistan, 2018). More recently, other SSI have arisen and are related to climate change, sustainability, or to the effects of pandemics.

When curricular content is taught in the context of an SSI, it becomes SSI-based instruction. As defined in the literature, SSI-based instruction "offers learning contexts that include both conceptual connections to science and ill-structured and compelling problems that engage learners in discussion, critical thinking, and decision-making" (Klosterman & Sadler, 2010, p. 1018). SSI-based instruction has been recognised as an educational practice with unique dynamics, such as setting the content to be learnt in the context of the SSI, and challenging students to adopt different perspectives on the issue throughout the lesson (Owens, Sadler, & Friedrichsen, 2019).

It is common that SSI-based instruction takes place as an educational innovation. In this context, it aims to improve science teaching by including as part of the usual teaching the new demands for students to deal with real-life, unresolved problems, and use scientific thinking. Examples of this specific application of SSI-based instruction take place in the context of interventions such as Professional Development (PD) courses (Friedrichsen, Ke, Sadler, & Zangori, 2020), or action-research, where teachers incorporate SSI-based instruction in their practice in collaboration with researchers (Lee & Yang, 2019). The number of such scenarios has increased rapidly in the last years, where more teachers are using SSI-based instruction in their lessons.

Educational research can help to understand and therefore intervene in the reality of SSI-based instruction when used as an educational innovation, to support it, maintain it, and develop it to its full potential. A substantial amount of the exploration of this topic focusses on the impact of SSI-based instruction on student learning (Fowler, Zeidler, & Sadler, 2009; Rudsberg, Öhman, & Östman, 2013; Troy D. Sadler, Romine, & Topçu, 2016; Vázquez-
Alonso, Aponte, Manassero-Mas, & Montesano, 2016), or on characterising how students learn with SSI-based instruction (Bossér & Lindahl, 2020; Eggert, Nitsch, Boone, Nückles, & Bögeholz, 2017; Peel, Zangori, Friedrichsen, Hayes, & Sadler, 2019; Troy D. Sadler & Zeidler, 2005). This research confirmed that as it is usual in educational innovation, teachers face challenges to deliver SSI-based instruction (Bossér, Lundin, Lindahl, & Linder, 2021; Kara, 2012; Rydberg, Olander, & Sjöström, 2018). This sets the need for deeper understanding of teachers, who behave as mediators between SSI-based instruction in theory and practice.

Research on teachers is developing, especially in secondary school (Albe et al., 2014; Garrido Espeja & Couso Lagarón, 2015; Gray & Bryce, 2006; Saunders & Rennie, 2013; Tidemand & Nielsen, 2017). Different constructs have been used to characterise SSI-based instruction, including teacher understanding (Tidemand & Nielsen, 2017), perspectives and strategies (Troy D. Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006), perceptions (Lee & Witz, 2009; Nida, 2020; Reis, 2013; Zangori, Foulk, Sadler, & Peel, 2018), conceptualisations (Garrido Espeja & Couso Lagarón, 2015), self-efficacy (Muğaloğlu, Küçük, & Güven, 2016), readiness to teach SSI (Oulton, Day, Dillon, & Grace, 2004), and experiences (Ekborg, Ottander, Silfver, & Simon, 2013).

These studies constitute a strong foundation for research into SSI-based instruction, but do not sufficiently enable the creation of a stable base of empirical evidence in which to ground knowledge about how teachers deliver SSI-based instruction. Moreover, the available studies are set in countries where SSI-based instruction is supported at an institutional or policy level, which makes this teaching practice less of an innovation than countries without such support (Ekborg et al., 2013; Tidemand & Nielsen, 2017).

As a way to fill this gap, the present study aims to characterise the delivery of SSI-based instruction as an educational innovation among secondary school science teachers in a comprehensive, systematic manner. To achieve that goal, it adopts a multi-dimensional approach to educational innovation, which is analysed from three perspectives, namely: 1) Objectives of SSI-based instruction, 2) Components of SSI-based instruction, and 3) Resistance to SSI-based instruction.

In pursuit of that goal, this qualitative, interpretivist study collects data from two educational interventions where in-service Spanish science teachers planned, delivered and reflected about lessons that used SSI-based instruction. These interventions constitute an example of
the delivery of SSI-based instruction as an educational innovation, since in Spain, SSI-based instruction is not promoted or reinforced (Vázquez-Alonso & Manassero-Mas, 2016).

Then, the expected and unique contribution of this research will be a characterization of how secondary school science teachers deliver SSI-based instruction as an educational innovation. Understanding this phenomenon should help to clarify how students come into contact with SSI in practice, which feeds back into the design of SSI-based instruction. Furthermore, it could support in the search for strategies that could help teachers to maintain, deepen and support SSI-based instruction.

Nevertheless, creating a comprehensive understanding of SSI-based instruction is beyond the goals of this dissertation. Rather, this study aims to be a first systematic attempt to the characterisation of secondary school teachers' delivery of SSI-based instruction from the specific point of view of educational innovation.
2. Research objectives

In order to address the problem identified above, the objective of this dissertation is to characterize secondary school science teachers' experience with SSI-based instruction. This characterization will provide insight that will help to develop an in-depth understanding of this educational practice, which is emergent but constantly growing in socio-educational contexts where SSI are not yet supported in the curriculum. On the basis of this understanding, guidelines could be found to promote and maintain it through policy development, as well as initial and continuing teacher education.

The main objective of this study can be defined as follows: to develop an in-depth understanding of how secondary school science teachers deliver SSI-based instruction when it is used as an educational innovation. The main research objective has been broken down into specific research objectives. The specific research objectives are based on smaller units, all of them working in the direction of the main research objective. For this study, the following specific research objectives have been defined:

- To approach SSI-based instruction as an educational innovation that pursues a set of objectives, is made of components, and encounters resistance.
- To characterise the sociocultural context where teaching SSI is seen as a way to innovate in science instruction.
- To identify, on the basis of a critical review of the literature, models for SSI-based instruction, and to choose and define a model to characterise it.
- To collect data about SSI-based instruction from in-service teachers in a rigorous and systematic manner.
- To apply the initial framework of analysis of SSI-based instruction to the analysis of empirical data from in-service teachers.
- To determine emerging categories in the framework of analysis of SSI-based instruction.

In pursuit of these objectives, the present research aims to contributing to a wider, ongoing goal of adapting formal education and in particular secondary school to the changes that take place in society, especially in the light of the need to become active, conscious and responsible citizens in the context of globalisation and in an interconnected world.
3. Context of the research

As it was explained in previous section, the present research is concerned with the pedagogical use of Socioscientific Issues (SSI), as expressed in SSI-based instruction. This phenomenon is approached in a specific socio-educational reality where science teachers teach SSI as something new, which they are experimenting with as a way to improve student learning. In other words, SSI-based instruction is not their usual way of teaching. To access this reality, the present study collected data from two educational interventions for teachers who were in this situation. More specifically, they all participated in the project "Equipping the Next Generation for Active Engagement in Science" (hereafter, "Engaging Science" or its acronym, i.e. "Engage"). This project constitutes the context of the present research.

3.1. The Engaging Science project

The Engaging Science project was an initiative contributing to citizen involvement in science, by means of teaching Socioscientific Issues (SSI) in secondary school science lessons. It had a budget of 2,804,226.01€, with a contribution from the European Commission (FP7 programme) of 642,459.18€. The project lasted from the 1st of January, 2014 to the 31st of March, 2017. It was carried out by a consortium made of fifteen (15) education and technological organisations, including the University of Barcelona, from thirteen (13) countries. All organisations were located in states of the European Union, one in Israel and one in Norway.

The main goal of the project was to help students become more engaged in current scientific and technological problems, by teaching SSI in science lessons. As such, the project was meant to contribute to an overall strategy of bridging the gap between scientific activities and citizens, known as Responsible Research and Innovation. To achieve this goal, the project targeted secondary school teachers as individuals, as opposed to bigger groups such as science departments or schools. The project objectives can be summarized as follows:

- Achieve a first layer of awareness and incorporation of SSI into science teaching practice across Europe

1 https://cordis.europa.eu/project/id/612269
• Support teachers in increasing their incorporation of SSI in their teaching in a qualitative way

In order to achieve these objectives, and on the basis of supporting teachers in the digital era, the project developed and implemented three actions, namely: 1) Open Education Resources (OER), 2) Professional Development (PD), and 3) Community (Ye, Recker, Walker, Leary, & Yuan, 2015). The OER are the Engage materials, and will be described in more detail in next section. The PD consisted of an online learning environment with information about the pedagogical principles of the Engage materials, as well as a guided process to plan or implement a lesson using one of them. The community strategy aimed to creating a network of innovative teachers who are interested and already have some training and experience in teaching SSI, so that they can support each other. All these strategies were implemented with the support of Information and Communication Technologies (ICT), which were mainly web-based.

3.2. The Engage materials

Instructional materials, also known as educative materials, are resources that support teaching and learning activities. These materials are especially useful for teachers, as they can use them to improve student achievement of learning goals by including them in planning their lessons. Instructional materials have been used to promote pedagogical innovation in science education as they provide teachers with a support to enact new practices (Schneider, Krajcik, & Blumenfeld, 2005).

The Engage materials are ready-made, self-contained lesson plans that help students develop science knowledge and skills related to a specific SSI, for example Fracking, the Ebola virus, or Genetically Modified Organisms (GMO). The materials were developed by professionals of the institutions participating in the Engaging Science project, including professional textbook developers. The full list of the SSI covered in the materials, including a description of each, is available in Appendix 1.1, and can be accessed at the following site: http://www.engagingscience.eu/es/.
3.2.1. Process of materials development

Throughout the duration of the Engage project, the Engage materials were developed and made accessible to teachers gradually. The process of developing each material was the following:

1) Brainstorming ideas of SSI that the material could focus on, based on their presence in public discussion, the media, or the interest that it could arise in students. The institutions involved in the Engage project voted to decide which SSI the material would be about.

2) Producing the material, including: presentation for the teacher, student sheets, and teacher guide. A few examples of the materials are available in Appendixes 1.2., 1.3., and 1.4.

3) Translating the material into local languages and localising its contents to different cultural contexts. This process included changing the references to food for different religions, or the degrees of temperature to warm or cold climate. There would be different versions of the material, one in English and one in the language of each institution participating in the project.

4) Publishing the material at the public online repository http://www.engagingscience.eu/es/. The materials were free to download and modifiable after registering for free, following the principles of Open Education Resources (OER).
3.2.2. Components of the materials

3.2.2.1. Learning objectives

Each material is linked to specific knowledge and skills that are covered in the Spanish curriculum. The relation between materials and the curriculum is key because it helps teachers to use the material if it deals with content they have to teach in that year. The materials aim to teaching knowledge and skills (Alcaraz-Dominguez & Barajas, 2016; Okada, Young & Sherborne, 2015). In terms of knowledge, they are inspired by Lederman, Antink, & Bartos (2014), as they aim at teaching the content knowledge that the SSI is related to, as well as the nature of such scientific knowledge. Accordingly, the materials include the following content:

- Technology impact: A reflection about how to minimise the undesirable effects of scientific and technological developments
- Big science: A reflection about the relation between science and society
- Values thinking: Considerations about the values involved in scientific activity
• Science Media: Considerations about the interpretation that the Media make of scientific information

In terms of skills, each material includes one or more of the following stages, which are inspired by the Inquiry-Based Learning approach:

• Interrogate sources
• Use Ethics
• Examine consequences
• Estimate risks
• Analyse patterns
• Critique claims
• Justify opinions
• Communicate ideas

3.2.2.2. Learning sequence

The Engage materials propose a way to address SSI through a process that is inspired by Inquiry-Based Learning. This model describes a set of stages by which students make use of the scientific process to make a decision about an SSI.

This strategy is characterised by posing an investigable question, that leads to data collection and analysis, and based on that the question is responded. This structure situates students as active agents in building their own knowledge based on a scientific way of thinking, where conclusions are drawn from evidence. When dealing with an SSI, this process has certain characteristics, for example the fact that the data collected is not always scientific, or that the conclusions drawn as a result of the data collection and analysis are not black or white.

3.2.3. SSI covered in the materials

A total of 30 materials were developed and published in the online repository. The downloads of the materials were monitored monthly. From those materials, 8-10 generated most interest, and they deal with the following issues: reducing the personal energy consumption at home, banning sugar drinks, the Ebola virus, a new neck condition associated with the use of mobile phone, electronic cigarettes, alternatives to plastic bags, having children with 3 parents, sun beds, and Genetically Modified (GM) foods.
In Appendix 1.1 there is a list of all materials with a short description. Appendixes 1.2, 1.3, and 1.4 present examples of 3 materials.
4. Formal aspects of the dissertation

4.1. Structure of the document

The present document follows the structure proposed in the last available version of the guidelines for doctoral dissertations by University of Barcelona (Universitat de Barcelona, 2019). Accordingly, it is structured in six chapters, namely: 1) Introduction and objectives, 2) Theoretical framework, 3) Method and research development, 4) Results, 5) Discussion, and 6) Conclusions. Each chapter has a cover with its title, and an introduction. Each chapter is divided in sections that are numbered and that start in a new page.

![Structure of the dissertation](image)

Figure 2: Structure of the dissertation

4.2. Language and formatting aspects

The present dissertation is written in British English, as it is the main language to communicate among researchers in the field of SSI and SSI-based instruction, for instance through journal publications and conferences. Nevertheless, the abstract is also provided in Spanish and in Catalan, which are the two official languages in the region of Catalonia, which
is where Universitat de Barcelona is located. Furthermore, seeing that the participants of this research are Spanish, the present document includes some terms in Spanish that have not been translated into English. In those cases, the words are in quotes and the rest of the sentence is written in a way that the meaning of the concept can be understood from the context. Teachers provided data in Spanish, which has been translated into English.

A few decisions were made in terms of the terminology used in this dissertation, which will be further reasoned in Chapter 2: Theoretical framework. Among them refers to the open discussion about whether to use "Socioscientific issues" or "Socio-scientific issues". In this regard, it was decided not to use a hyphen in this dissertation, following the argumentation presented by one of the main authors in the field, Dr. Dana Zeidler in his chapter about SSI in the Handbook of Research in Science Education, volume 2 (Zeidler, 2014).

Furthermore, Socioscientific issues are often referred in this document as SSI, an acronym that also plays the role of an adjective to other concepts that are used in this research, such as SSI-based instruction, SSI lessons, or SSI materials. The singular and plural forms of this concept are both represented with the acronym SSI, as it has been considered that it is possible to infer them from the context.

An impersonal use of language has been chosen as predominant in this dissertation, except for sections where presenting a subjective view was the priority, such as the section discussing the role of the researcher that is part of Chapter 3: Methodology and research development. For this reason, the use of the passive voice has been necessary, although and effort to facilitate reading has been made to use the active voice as much as possible.

An effort has been made so that the language used in this dissertation also caters for gender issues. For instance, the participants have been anonymised by receiving a unique ID for each case, namely teacher "1T1", teacher "1T2", etc. as a way to preserve their privacy. In some cases the gender has been used to avoid repetition of these IDs in a sentence. In those cases, participants are referred to as he / she and him / her according to their demographics.

The font type and size, as well as the titles, figures and other formatting aspects of this dissertation follow the guidelines for PhD dissertations from the Faculty of Education at Universitat de Barcelona (Universitat de Barcelona, 2019). References are listed following the 6th edition of the American Psychological Association.
A system of brackets and parenthesis was determined to present teachers' quotations in a way that kept the original meaning while making it understandable for the reader, which can be found especially in Chapter 4: Results. According to this system, omitted, irrelevant text appears in parenthesis. For example, the original quotation “Ethical discussions about genetics, a topic where there is a lot of misinformation, are not grounded scientifically” (T9) has been shortened to keep the attention in the main point of the statement as follows: “Ethical discussions about genetics (…) are not grounded scientifically” (T9). Similarly, teachers make references to concepts that are missing in the specific sentence that has been chosen as a quotation. In that case, the concept they are referring to is presented in brackets. Seeing that in Spanish language the subject of a sentence can be inferred from the verb, brackets are frequently used in this dissertation to clarify who is the subject of the sentence. For instance, to make clear that the teacher is talking about SSI-based instruction, the following editing was made: “[it] allows students to develop scientific skills such as argumentation and reasoning” (T15).
CHAPTER 2

THEORETICAL FRAMEWORK
Chapter 2: Theoretical framework

This chapter critically reviews, analyses and synthesizes the theoretical positions and empirical studies in which this study is based. To that goal, it is divided in five parts.

The first part, entitled "The societal aspects of science", aims to present an overview of the societal context where this investigation is embedded. This context is characterised by an increasingly strong importance of science and technology in society as a driving force for economic growth.

The second part of this chapter describes the broad educational context that surrounds SSI-based instruction, which is science education. Since SSI-based instruction is seen in this study as an educational innovation, the second part of this chapter describes formal science education in the context of educational change. To that goal, the concepts of Competence-Based Learning (CBL), Scientific Literacy (SL) and educational innovation are described.

The third part of the theoretical framework of this dissertation establishes the theoretical groundings supporting the understanding of science teachers that is made in this study. Science teachers are considered as professionals, whose task is specified in terms of competences that are stated in educational policy and initial teacher education. To develop these competences, teachers need knowledge. For this reason, the main types of teacher knowledge are described, including Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK).

The last section of this chapter is devoted to establishing, at a conceptual level, the interpretative framework of this investigation. In other words, the three dimensions that have been chosen to analyse the phenomenon of SSI-based instruction as an educational innovation are explained in detail, namely objectives, components and resistances.
1. The societal aspects of science

As scientific activities become important in a society, a reflection process has taken place about its purposes and products (Monsonis-Payá, García-Melón, & Lozano, 2017). The relation between science and society as a human activity has been discussed for a long time in academia, from disciplines such as philosophy, epistemology, and sociology. Some perspectives which have studied this problem are: Technology Assessment (TA) (van Wezel et al., 2017), Public Engagement (PE), Science, Technology and Society (STS) studies (Grunwald, 2011), Public Understanding of Science (PUS), Science Policy and Innovation Studies (SPIS), and Socio-Technical integration (Owen, 2014). A growing interest has been observed in the last decades to articulate these reflections around the concept of the societal aspects of science.

1.1. The importance of research and innovation nowadays

A common trend in public policy is to associate science and technological activities to economic progress and societal growth. This situation is especially common in post-industrialized, knowledge-based economies, where knowledge creation, especially in experimental sciences, can help to tackle global challenges in important fields such as health and disease or climate phenomena, among others. In these societies, technological developments can help to improve important activities such as communications, transportation, and digital data management, including Artificial Intelligence (AI).

An indicator of the importance given to these activities in European policy and in most of its state members is how they are named. Different terms have been deployed, including "science", "scientific activity", "Science, Technology, Engineering and Mathematics" (STEM), and "Research and Development" (R&D). Since 2010, at high levels of governance such as European polices, the term "Research and Innovation" (R&I) is used (European Commission. Directorate-General for Research and Innovation, 2011; Owen, 2014; Stahl, 2013). Including traditional "science" and innovation under the same policy reflects how scientific activities, usually known as research, are associated with innovation activities, which have a sense of improving our lives.

Another indicator of the importance of R&I in Europe is the amount of public funding that it receives. The policy of reference at the time of writing this report is the "Horizon 2020 -
the Framework Programme for Research and Innovation (2014-2020)". This funding framework responded to the “Innovation union” strategy, which conceived innovation as a way to improve Europe's competitiveness and create jobs after the economic crisis (European Commission. Directorate-General for Research and Innovation, 2011). According to this framework, the EU committed to invest 3% of its GDP on R&I (European Union, 2013b).

Following these supra-national policy, European state members, especially in the North of Europe, worked towards achieving this goal. In Spain, the public funding devoted to R&I represented 1.25% of Spain's GDP in 2019 (Instituto Nacional de Estadística, 2019). Even if this figure is far from the European Union goals, it increased every year since 2014, and such increase has been higher since 2016.

1.2. Approaches to address the societal aspects of science

In highly science and technology-ruled economies like those described in previous section, it is frequent that the products of scientific research or innovation create debate, as these processes can't be isolated from society's needs or values. A recent example is that of the Covid-19 pandemic, which triggered discussion about several topics, including how it started, the effects of the virus in the human body, as well as vaccine development and distribution. All the while, other, previous discussions remain open about topics such as the threats that artificial intelligence can pose in people's jobs, the potential accidents of self-driven cars, or the possibility to travel to space or live in other planets. These questions do not have a single answer, either because the scientific knowledge available is unclear or because strictly scientific knowledge is not enough to accurately address it, and other aspects need to be taken into account (Steffen & Hößle, 2014). These debates, and thus citizens' discussion about scientific and technological matters, have only become more common as social media grow and develop as one of the main ways to communicate and of creating opinion.

Some topics have a high level of agreement, especially among young adults. For example, the call for actions to fight climate change has been led in the last years by younger citizens. Other topics, however, generate more discussion. Citizens questioning decisions that are made in science has led to rejection of certain scientific advancements or technological innovations, thus losing the investment that was made. In the case of the Covid-19 pandemic, the growing scepticism towards vaccination could be an example. This problem, however,
has existed for decades. In order to solve it, changes were proposed in how R&I are developed, so to bridge the gap between these activities and the concerns, opinions and values of the citizens who are not professionally involved in them. Two main views can be identified, which can be described as 1) the "science outreach" approach, and 2) the "science collaboration" approach.

1.2.1. The "Science outreach" approach

The "science outreach" approach is represented by policies that aim to engage citizens in R&I. These policies start from the assumption that science and society are separate entities with different missions and purposes. In these approaches "the rest of society" would be those who do not devote their professional activity to science. Early visions of citizen engagement consider citizens as consumers, as the market that adopts the results of scientific research and innovation. In this model, the rationale underpinning citizen involvement in research is to minimise the risk of rebuttal of new products or, in other words, to make sure that the investment in research leads to an economic return. Authors find this view in early programmes in the 80s, with the realisation that discoveries in emerging sciences such as genomics could have ethical and societal implications (Romero-Ariza, Abril, & Quesada, 2017). This has been also called the consequentialist approach to responsibility (Owen, Macnaghten, & Stilgoe, 2012; Tassone, O’Mahony, McKenna, Eppink, & Wals, 2017) and is represented in figure 3 below.

![The science outreach approach](image-url)

Figure 3: Approach in which science and society are separated
The "science outreach" approach comprises policies that describe different levels of citizen involvement in R&I. The first level can be described as "communication of results", which responds to the view of citizens as contributors. If research is funded by tax, contributors should know how that money is used (de Saille, 2015). This approach is represented in policies that follow the Ethical, Legal and Social Implications of science (ELSI) approach, which was also called Ethical, Legal and Social Aspects of science or ELSA. These policies took place in the US and Europe, respectively, in the 90s and early 2000s (Zwart, Landeweerd, & van Rooij, 2014). This is considered as a unidirectional approach where citizens are informed about the results of R&I.

The second level of citizen engagement in science is based on a two-sided communication between scientists and citizens. This vision has been associated with EU’s funding programme FP6 (Burget, Bardone, & Pedaste, 2017), and carried on to Framework Programme 7 or FP7 (de Saille, 2015). Rodríguez, Fisher, & Schuurbiers (2013) observed that throughout the first decade of the 2000s the EU started to include society among the goals of research and development activities, along with those belonging to research and development themselves, and widened the range of areas accountable for what was called socio-technical integration. For instance, the EU promoted a greater engagement of stakeholders such as patient groups in health research, or companies, in a deeper way, i.e. not only as “receivers” of R&I activities but as participants in a process of dialogue (Rodríguez et al., 2013).

Recent examples of the goal to integrate citizens in R&I processes can be found, such as the Eurobarometer on public perceptions of science, research and innovation, with more than 27000 respondents (European Comission, 2017). The objective of this survey was to inform the priorities to be researched, which would receive funding through the funding call Horizon 2020. The past EU strategy known as "open innovation" also reflected the assumption that science "reaches out" to society, as it aimed to "opening up the innovation process to people with experience in fields other than academia and science”

1.2.2. The "Science collaboration" approach

Another way to address the social aspects of R&I is by perceiving science and society at an equal level. In this scope, scientists (through the institutions where they develop their activity

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and the rest of society collaborate in R&I (Apotheker et al., 2017). R&I is not possible without these social actors, who can be associations, foundations, NGOs, or individual citizens (European Commission. Directorate-General for Research and Innovation, 2015). In other words, this approach represents a substantial shift that conceives R&I activities as part of society, thus moving on from the vision of R&I as a superior activity which necessarily leads to wellness and growth (López-Pérez & Olvera-Lobo, 2015). This change is due to accepting that traditional science governance schemes don't work anymore in an uncertain world (Stahl, 2013a; Stilgoe, Owen, & Macnaghten, 2013). This conceptualisation is shown in figure 4 below.

Figure 4: Approach of interaction between science and society

1.3. Responsible Research and Innovation (RRI) to address the societal aspects of science

From the two approaches presented above, science collaboration is the current one since about a decade ago. In Europe it is called Responsible Research and Innovation, or RRI (de Saille, 2015; European Commission. Directorate-General for Research and Innovation, 2015; Gorghiu, Dumitrescu, & Petrescu, 2016; Grunwald, 2011; Owen, 2014).

1.3.1. Conceptualisation of RRI

RRI aims to ensure that R&I activities are consistent with the values, principles and priorities of the society in which they take place (Domènech-Casal & Lope, 2015; Figueiredo
The definition of RRI that gathers most consensus in the literature is from von Schomberg (2013): “a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)” (Bayram-Jacobs, 2016; Kikis-Papadakis & Chaimala, 2016). The main RRI keys are (Sutcliffe, 2011):

1. Social and environmental benefit
2. Involving society
3. Explore social, ethical and environmental issues
4. Develop effective response
5. Openness and transparency in the R&I process

Compared to other proposals for an integration between science and society, which are inspired by the consequences of R&I, RRI has a prospective goal, as it "aligns with the complex society of today, that acknowledges the importance of knowledge while accommodating its limitations, that allows for a deeper reflection about ways of doing and being, and also allows for the cultivation of social values and for socially and planetary relevant responses" (Tassone et al., 2017, p. 5). The prospective nature of RRI has been interpreted as a change of the mission of R&I towards addressing societal challenges, which evolve as society evolves (Stahl, 2013a).

1.3.2. RRI in practice

Since RRI was introduced, authors have said that judging by its name, it seems obvious, as it would be difficult to stand behind a vision promoting to carry out research and innovation irresponsibly (Owen, 2014; Owen et al., 2013). However, the introduction of the concept of responsibility in R&I implies defining the relation between science and society through values as opposed to other criteria. Values are subjective concepts, defined by a society, and therefore change according to the cultural context. Therefore, in order to understand the societal model of RRI, there is a need to understand the meaning of the word "responsibility" (Monsonís-Payá et al., 2017). In order to clarify what the term "responsibility" means in R&I, the views of different authors were reviewed, and they are synthesised in table 1 below. The
main views have been organised following Owen et al. (2012), who claim that the discourses in the literature about RRI can be divided into the references to RRI products and processes.

<table>
<thead>
<tr>
<th>Author</th>
<th>R&amp;I products</th>
<th>R&amp;I processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>von Schomberg, 2013</td>
<td>Ethically acceptable Sustainable Socially acceptable</td>
<td>Mutual responsiveness Acceptability Sustainability Desirability</td>
</tr>
<tr>
<td>Owen et al., 2012</td>
<td>Address societal challenges</td>
<td>Anticipatory Reflective Deliberative Responsive</td>
</tr>
<tr>
<td>Klaassen et al., 2014</td>
<td>Ethically acceptable Sustainable Socially acceptable</td>
<td>Diversity &amp; Inclusion Anticipation &amp; Reflection Openness &amp; Transparency Responsiveness &amp; Adaptive change</td>
</tr>
<tr>
<td>Romero-Ariza, Abril &amp; Quesada, 2017</td>
<td>Socially desirable Sustainable Ethically acceptable</td>
<td>Diversity &amp; Inclusion Anticipation &amp; Reflection Openness &amp; Transparency Responsiveness &amp; Adaptive change</td>
</tr>
</tbody>
</table>

Table 1: Synthesis of the views about RRI in the literature (source: prepared by the author)

In terms of product, there is consensus between the authors about the need for ethical acceptability, sustainability and social acceptation. In terms of process, the following most common characteristics can be observed:

- **Anticipatory**: describing and analysing those intended and potentially unintended impacts that might arise, be these economic, social, environmental or otherwise;
- **Reflective**: reflecting on underlying purposes, motivations and potential impacts;
- **Open / transparent / deliberative**: inclusively opening up visions, purposes, questions and dilemmas to broad, collective deliberation through processes of dialogue;
- **Responsive / adaptive**: using this collective process of reflexivity to both set the direction and influence the subsequent trajectory and pace of innovation. Responsiveness suggests that all societal actors take part in the R&I process, from companies to governments, and non-profit organisations. “RRI is built upon a model where everybody is involved in discussing both risks and positive outcomes, and it is
additionally assumed that participants in such discussions will feel that they have been listened to.” (Lundström, Sjöström, & Hasslöf, 2017, p.17).

In practice, these principles are applied in R&I policies. These are mainly public and institutional. How RRI is developed in these two domains at the time of writing this report is described in the following subsections.

### 1.3.2.1. RRI in public policy

As a way to promote and reinforce Responsible Research and Innovation (RRI), some of its principles have been applied in recent public policy. In the European Union, the European Commission is the main executor of R&I policies (European Union, 2013a). The European Union has publicly expressed how it caters for RRI in a collection of laws, activities and initiatives (European Commission. Directorate-General for Research and Innovation, 2015):

- the introduction of RRI as a cross-cutting principle in Horizon 2020 in its entirety;
- specific actions and initiatives from the Commission to implement RRI as a cross-cutting principle in the various work programmes of Horizon 2020;
- activities funded by the various work programmes of Horizon 2020 in which RRI aspects have been part of the objective or expected impact of the call;
- specific actions and initiatives by DG Research and Innovation on the six keys of RRI;
- the implementation of the ‘Science with and for society’ programme of Horizon 2020;
- the activities funded by the ‘Science with and for society’ programme of Horizon 2020.

Considering Horizon 2020 as the main policy describing the objectives of R&I activities in Europe is a useful way to understand the presence of RRI in EU policy. It includes two specific objectives, namely: 1) spreading excellence and widening participation, and 2) Science with and for Society (SwafS). SwafS is the regulation establishing RRI. It aims to "build effective cooperation between science and society, to recruit new talent for science and to pair scientific excellence with social awareness and responsibility" (European Union, 2013b). SwafS is split in three work programmes. In the first working programme (corresponding to the period 2014-16), the four calls for funding support RRI: 1) making
science education and careers more attractive for young people, 2) promoting gender equality in research and innovation, 3) integrating society in science and innovation, and 4) developing governance for the advancement of RRI. The second period (2016-17) is informed by a strategic orientation "Open debates and learning by doing along the lines of Responsible Research and Innovation". This means that RRI is part of the objectives of the working plan, and it is present in the four themes that constitute the calls for funding. In 2018-20, RRI still appears as an objective to pursue so to achieve that R&I activities are conducted with and for society (European commission, 2017). As Monsonís-Payá et al. point out, this shows that the current Horizon2020 funding programme "represented a milestone in the consolidation of RRI standing in the jargon of the policies of research and innovation in Europe" (Monsonís-Payá, García-Melón, & Lozano, 2017, p. 2).

Although RRI is a relatively recent policy, EU strategies are monitored. Some of the indicators to monitor the achievement of Horizon 2020 goals have to do with RRI: "private sector participation, gender equality, widening participation" (European Union, 2013c, p. 111). Further, The EU made a first step by determining indicators of success of RRI policy (European Commission. Directorate-General for Research and Innovation, 2015).

As a part of the European Union, member states include RRI principles in their National Policies. The Netherlands (Grunwald, 2011; Zwart, Landeweerd, & van Rooij, 2014), the UK (B. C. Stahl, 2013a) and Norway (Owen, 2014) are especially well-known for their RRI compliant policies. There is evidence that public policy in Spain also embraces the RRI vision. The main reference document at the moment of writing this report is the 2011 Science Act, which regulates scientific activity performed in the country. The Act is further developed in the National plan of Scientific and technical research and innovation 2013-2016. Revuelta (2013) reviews these documents in the light of the six RRI dimensions from FP7. In the views of this author, “The Science Act contains numerous references to those six concepts (...) as well as other elements that we can also consider as consubstantial to RRI, such as inclusiveness, sustainability, cooperation, transparency, and a focus on future” (Revuelta, 2013, p. 2).

1.3.2.2. RRI in organisations and institutions

The impact of RRI in society has only increased in the past decade. Universities and other research institutions developed RRI plans. Frameworks exist to apply RRI principles to the industry, such as the RRI maturity model from Stahl et al. (2017). The model can be used by
an organisation to self-assess their level of compromise with the RRI principles in three categories, namely purpose, processes, and products of their activity. Each category is ranked in five levels, from unaware to strategic, thus showing to what extent the RRI principles are integrated in each category.

Specific RRI plans have been included in research projects themselves (see Rose, 2014). In terms of research fields, RRI principles are being applied to fields such as Information and Communication Technologies, as reported by Stahl (2013) and Nanotechnology development, for example van Wezel et al. (2017). RRI has been applied to companies whose activity has a certain repercussion in society, through terms such as Corporate Social Responsibility (CSR), as reported by van de Poel et al. (2017).
2. Formal science education in the context of educational change

One of the priorities of educational systems worldwide is to help students be sufficiently familiar with science to be a fully integrated member of society. All the while, the role of science and technology in societies has evolved in the last decades, as shown in section above. As a consequence, educational systems adapt to these changes. In this section the main concepts that are relevant to understand formal science education in the current context of change are described.

2.1. Competence-based learning

Basic competences are the main way to describe the objectives of formal education at the moment in most education systems in Europe, since they were used in the EU competence framework for lifelong learning (European Council, 2006). Competences refer to "the mobilisation of knowledge, skills, attitudes and values to meet complex demands" (Organisation for Economic Co-operation and Development, 2018, p. 5). Competences have been part of official curricula for about two decades, thus constituting a relatively recent incorporation to an otherwise content-focussed specification of the contents of secondary school. As such, key competences brought about changes that affect school practice. For example, using more active learning methodologies and designing learning experiences that include relations between the school subjects (Gordon et al., 2009).

In the case of science education, one of these changes is to blurry the boundaries between knowledge fields. The most common is to group Science, Technology, Engineering and Mathematics (STEM) (Tseng, Chang, Lou, & Chen, 2013). In the US, STEM is considered a way to “Increase students’ understanding of how things work and improve their use of technologies” (Bybee, 2010). Integration with other disciplines outside experimental sciences, for example arts, has been discussed as part of a competence-based approach to formal education. In last years in the concept of STEAM (Zeidler, 2016). The impact of this change in educational practice is the need to use integrated learning approaches, such as project-based learning, or at the level of school organisation, where a strategy has to be defined so that students develop each competence sufficiently across subjects.
2.2. Scientific literacy

Formal science education is guided by the overall goal of helping students develop scientific literacy (Deboer, 2000). As a culturally constructed concept, scientific literacy is defined differently depending on the time and socio-cultural context. The present section defines scientific literacy as it is generally stated in the curricula of European countries and in Spain in particular, at the moment of carrying out this investigation.

2.2.1. Definition

Several definitions about scientific literacy coexist, sometimes within a relatively uniform socio-cultural context (Siarova, Sternadel, & Szőnyi, 2019). Because of its influence, scope and impact in educational policy, the operationalisation from the PISA test can be used as representative of how this construct is defined in Europe: "Scientific literacy: the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (Organisation for Economic Co-operation and Development, 2019, p. 15). This definition is the result of a process of an ongoing reflection and debate about what it means to be scientifically capable (Miller, 1989, quoted in Laugksch, 1999; Bennássar, Vázquez, Manassero, & García-Carmona, 2010; Sjöström, 2017).

A shift towards "scientific literacy for citizens" or "scientific literacy for citizenship" has been observed in educational systems in Europe (Blanco-López, España-Ramos, González-García, & Franco-Mariscal, 2015). The concept of "citizen" has guided and informed the specifications of formal educational systems, curriculum development, and international assessment tests for a few decades now (Organisation for Economic Co-operation and Development, 2019). The concept of citizen is based on the idea that basic, compulsory education must enable students to be part of today's society. The definition of what it means to be a citizen, and hence how formal education can prepare students, is affected by changes in society. One of these changes is the increasingly important role of research and innovation in society. As a consequence, the definition of scientific literacy changed.

Some authors have described this process as a continuum between “Visions I and II” of scientific literacy (Lundström et al., 2017; Presley et al., 2013; Romine et al., 2017; Sadler & Zeidler, 2009; Zeidler, 2014). Vision I is traditional, close to the traditional science disciplines. In contrast, vision II is progressive as it incorporates the social dimension of
According to this vision, students must develop scientific knowledge, but also as other types of knowledge and skills that will help them perform scientific inquiry and think scientifically. As expressed by Saunders and Rennie in their revision of the definition of scientific literacy (2013): "Although there are different emphases in definitions for scientific literacy, they are consistent in that they focus on science education for future citizens, not just future science professionals" (p. 255).

In recent years, vision II has been said to be insufficient considering the developments of society. Vision III of scientific literacy has been proposed, which emphasizes "socio-political actions, philosophical values and/or existential perspectives" (Sjöström, 2017). A similar operationalisation of scientific literacy has arisen in the literature in recent years, which is known as "Functional Literacy (FSL)". Academics use this term to refer to current views of scientific literacy in American educational theory and policy (Sadler, Barab & Scott, 2007b; Saunders & Rennie, 2013; Zeidler, 2014).

2.2.2. Scientific literacy in educational policy

Research has been devoted to understanding to what extent theoretical reflections about the components of scientific literacy for citizenship are present in educational policy. One of the key competences in the European recommendation to state members is "Mathematical competence and competence in science, technology, engineering" (European Commission, 2018a), as defined by "the ability and willingness to explain the natural world by making use of the body of knowledge and methodology employed, including observation and experimentation, in order to identify questions and to draw evidence-based conclusions" (European Commission, 2018b, p. 3).

The societal aspects of science are increasingly included in the PISA test. Garrido and Simarro (2014) observe that in the previous PISA framework, from 2007, knowledge was divided between knowledge “of” science and “about” science. Knowledge about science would be equivalent to Nature of Science (NoS). The current PISA framework breaks down the knowledge “about” science in two categories, namely procedural and epistemic knowledge, which are put on the same level of the hierarchy as the knowledge “of” science (i.e. conceptual knowledge). Although in a modest way, this change has also been observed in the Spanish national curriculum (Vázquez-Alonso & Manassero-Mas, 2016; Vázquez-Alonso & Manassero Mas, 2017). In fact, in general, NoS has been considered insufficiently
covered in European national curricula in the light of the increasing role of science and technology in our lives.

2.3. Educational innovation

Educational innovation is often defined in comparison to other types of educational change such as reform or renovation. With respect to these, innovation attempts to improve educational processes or results, to increase efficiency in a specific context (Jiménez-González, González Soto, & Fandos Garrido, 2012). In the case of formal education, innovation lasts a shorter time than reform or renovation and it is more focused on the participants of the teaching and learning process than in other, structural components.

Educational innovation is progressively becoming a structural component of educational systems worldwide. It is a priority for the European Union, as well as for its state members, as it ensures that education is in constant renewal so that it is consistent with the needs and developments that take place in society (Jiménez-González et al., 2012). At the European Union level, several initiatives work to support educational innovation, including grants for developing innovative projects in all levels of education, strategies to increase the presence of technology in education, and other actions such as supporting entrepreneurship. In terms of its state members, innovation in education is generally supported by policy and funding, especially with regards to digital education (European Schoolnet, 2020).

2.3.1. Models of educational innovation

As a deliberate attempt to improve an educational reality, educational innovation unfolds differently, depending on where it starts. On the basis of the work by Huberman, Havelock and Morrish, the authors Jiménez González et al. (2012) define three models of educational innovation.

The first model is described as "research and development". In this model, the innovation process is linear. It starts with a discovery that it is finally implemented in the reality that is concerned with. The process follows a sequence of steps. The first step is the research that will lead to developing knowledge about the reality that wants to be improved. The second step consists of designing the innovation process, put it into practice, and evaluate it. In the third step, and on the basis of the results obtained in the previous step, the innovation process is promoted among the professionals that are going to put it into practice. This step
often involves training these professionals, so that they apply the innovation correctly. Last, the fourth step involves that these professionals assimilate the innovation and they incorporate it in their usual practice, without the support of the promotors of the innovation.

According to the authors, the "research and development" model relies on the educational professionals being passive actors in the innovation process, and may cause a gap between the innovation and the characteristics of the environment in which it will be applied. To overcome these weaknesses, other innovation models were developed.

The second model of educational innovation is known as "social interaction". It is similar to the first model, because it follows a linear process where the school implements an innovation that has been designed and tested somewhere else. However, in this case, the innovation is discovered in another school. This fact is expected to bridge the gap between the developers of the innovation and those who implement it, assuming that schools are at the same level of hierarchy, as opposed to the innovation being developed for example by educational researchers.

The third model that the authors present is known as "problem solving". This model conceives the innovation process as drastically different from the two previous models, since the innovation starts in the actual context where it will be applied. The process is made of six steps. First, a need or problem arises in the context, and a call to take action about it. Second, a diagnose of the need is made. Then, solutions are proposed. After that, the innovation is adopted. The fifth step consists of a test where a possible solution is applied to the reality. The sixth and last step is the evaluation of the satisfaction of the users, in order to see if the problem was solved through the innovation. Once this last point is completed, the situation goes back to point 1, therefore presenting a view of the innovation process as an ongoing cycle.

### 2.3.2. Opposition to educational innovation

A common characteristic of educational innovation as an educational practice is that it takes place as part of a reality that already exists. This is true for all innovations, regardless of the model they follow. This way to look at educational innovation is built on the basis that teachers have a teaching practice that they have been developing before the innovation, students have a way of learning that was there before the innovation, and there is a specific
school organisation that was established before the innovation. Therefore, in order to design or characterise educational innovation, it is important to consider these oppositions.

More specifically, when it comes to analysing these sources of opposition, it is useful to understand the educational phenomenon as a network. According to González-Soto, education is a system composed by the following aspects: a) The context: Values, objectives of formal education; b) The needs of the participants; c) Relations between teachers and students and between teachers and other teachers and coordinators; and d) Contents of learning; teaching strategies; and assessment (1989). These elements are interconnected, so that changes in one affect the others. Therefore, in order to understand an innovation in formal education, it is necessary to observe not only the aspect in which the innovation takes place, but how it affects the others, and how the others affect it.

2.3.3. In-service teacher Professional Development (PD) as a context for educational innovation

The role of teachers has been considered crucial in educational innovation. According to Fullan and Hargreaves’ foundational work, the authors, teachers are the mediators between the curriculum and the students, thus becoming necessary collaborators in educational change (1992). In this context, teacher professional development can be defined as a way to influence teachers’ knowledge and practices. Especially in innovations following the "research and development" model presented above, authors recognise the important role that teacher learning can play in the implementation of the innovation in practice (Bakkenes, Vermunt, & Wubbels, 2010; Mamlok-Naaman & Hofstein, 2016).

Based on this principle, one of the most common educational intervention strategies to bring educational innovation into practice is through educational interventions targeting teachers, mostly in the form of in-service Professional Development (PD). Most of this PD, however, is practice-based, meaning that it involves teachers trying something new in the classroom. These approaches are based in the fact that there is a reciprocity between what teachers know and what they do, where one influences the other and vice versa, as an experience-based approach to teacher learning (Guisasola, Barragués, & Garmendia, 2013; Henze, van Driel, & Verloop, 2008b; J. H. van Driel, Verloop, & de Vos, 1998). One of the most detailed models describing this cycle is from Clarke and Hollingsworth (2002). It proposes four domains to be taken into account to understand teachers’ professional development. The
personal domain is located in teachers’ minds, thus referring to teachers’ knowledge, beliefs and attitudes. The external domain includes information which comes from outside teachers’ mind, i.e. external sources of information or stimuli. The domain of practice refers to what teachers do, as expressed in their classroom practice. Last, the domain of consequence refers to the results of a changed perception which comes as a result of salient outcomes related to classroom practice. The domains are connected by enactment and reflection. The personal domain affects and is affected by the external domain, the domain of consequence and the domain of practice. This means that knowledge, beliefs and attitudes play a central role in shaping the external stimuli received by the teacher, as well as the outcomes and the classroom practice that will be performed. In the same way, these 3 domains have an impact in teachers’ knowledge, beliefs and attitudes towards teaching.

As a consequence, these PD scenarios constitute instances of educational innovation, to the extent that teachers are trying something new in the classroom. Indeed, supporting teachers in improving the quality of their teaching and adapt to the evolving students' needs is a priority in most European countries, which is reflected in the constant offer of Professional Development (PD) programmes supported by public funding (Education Audiovisual and Culture Executive Agency, 2011).
3. Socioscientific Issues (SSI) in science education

Socioscientific Issues (SSI) are "complex and contentious social issues with substantial connections to science ideas and principles" (Zeidler, 2014, quoted in Sadler, Foulk, & Friedrichsen, 2017). SSI are discussed not only in highly scientific and technological societies, but in those where public debates are common. In these contexts, SSI become opportunities for citizens to form opinions about scientific topics and make decisions (Owens, Sadler, & Zeidler, 2017). In Europe, although SSI have been discussed for decades, an increase of SSI has been observed since twenty years ago, due to a process where science and technology a) become more present in societal and political domains, and b) are included in the political agenda and as an indicator of economic growth and progress (Aibar, 2002).

SSI are socially constructed or, in other words, what constitutes an SSI in a given time and socio-cultural context may not be so in another one. However, some SSI become common in post-industrialized, knowledge-based societies. The most recent example of SSI is the Covid-19 pandemic. Other SSI that remain present are related to climate change, Genetically Modifying Organisms (GMO), or fracking. Typical SSI deal with scientific disciplines that traditionally have been a concern or a first need in a society because they affect a majority of people or threaten human lives directly, such as health issues or environmental issues (Kolstø, 2001).

There is an agreement among theorists that SSI are controversial (Díaz-Moreno & Jiménez-Liso, 2012; Evagorou, Jiménez-Aleixandre, & Osborne, 2012; Oulton, Day, Dillon, & Grace, 2004; Sadler, 2004). On the basis of previous conceptualisations of SSI, Aibar (2002) argues for three main types of controversial SSI: a) those about the moral, ethical or religious implications of certain experiments or research lines, such as human cloning; b) those concerning the opposed views between the protecting the environment and other, political priorities, such as waste processing; and c) those regarding the risks of certain industrial or commercial practices for humans' health, such as meat consumption or mobile phone radiation.

The introduction of SSI in education goes back to the late 80s as a way to renew science education so that students can make real-world decisions using knowledge both about the physical and the social world (see Fleming, 1986b and 1986a). Since then, SSI have been in the centre of a reflection about how to make science education more consistent with
developments in society that point to a greater role of science and technology in our lives. To date, SSI is a relatively young construct in educational research. For example, SSI are often defined using different concepts such as dilemmas (Alcaraz-Dominguez & Barajas, 2021), Science in Context (L. Bencze et al., 2020), Socially Acute Questions (SAQ) (Sadler, 2009b), or Socioscientific Topics or SST (Wan & Bi, 2020).

Indeed, the definition of SSI from the perspective of educational intervention and innovation is not clear in the literature: "While most teachers generally accept the notion that ethical considerations do impact the practice of science, how to convey and express that in the context of day-to-day science teaching is not well understood" (Zeidler, 2014, p. 705). For some authors, the most appropriate SSI to address in the science classroom are related to science in the making, which means that the scientific knowledge is still under development (Díaz-Moreno, Caparrós Martín, & Sierra Nieto, 2019; Ekborg, Ideland, & Malmberg, 2009).

As a way to clarify this issue, this section presents the two main conceptualisations of SSI in education that can be found in the literature. These are a) SSI as a way to renew the curriculum, and b) SSI-based instruction.

### 3.1. SSI as a way to renew the curriculum

A systematic analysis of the literature reveals that a substantial amount of the discussion about SSI as applied to education focuses on how to adapt the science curriculum so that students become capable to deal with SSI in their lives. These authors maintain that SSI exist in society and students must be prepared to deal with them, including making decisions (Aikenhead, 1985).

Authors who support this view start from the assumption that SSI are one of the consequences of conceiving science as an inherently human activity, which can't be detached from the values of the sociocultural context in which it is developed. In this understanding, the more science is conceived as a culturally constructed, the more it is tied to the values and needs of society. This clashes with the traditional science curriculum, which was thought to teach students universal, factual scientific knowledge. The discussion about applying SSI in education from this perspective point out to the knowledge, skills, attitudes or competences that students need to navigate a world where science and technology have a bigger impact in their lives. Works on this direction highlight those aspects of the science curriculum that help students deal with SSI (Sadler & Zeidler, 2009). However, a diversity of approaches have
been reported. Lundström, Sjöström, and Hasslöf (2017) describe 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's Socially Acute Questions or SAQ (Simonneaux, 2011). A more purist approach is held by Zeidler, Applebaum, & Sadler (2011), who talk about the SSI-driven curriculum, which puts SSI in the center of the science education curriculum design.

This way to conceive SSI in formal education has been said to be a heir of previous, society-inspired proposals to formal science education curricula. Mainly, it has been related to Science, Technology and Society (STS) approaches, or STSE for those who add the component "Environment" (Pedretti & Nazir, 2011). STS did an important task in making science more relevant to students, this is, showing the usefulness of learning science because it affects our lives, therefore having scientific skills can help solve problems we care about (Mansour, 2009; Membiela, 1997). It starts from the assumption that in order to learn science theories and models, it is not enough by observing the environment but to develop a proactive attitude towards finding out how to know what we don’t know (Sanmartí, 2009).

Essentially, the contribution of SSI to science education is unique in that it builds on the STSE approach, making students' moral and ethical development part of science education on the assumption of an interdependence between science and society (Zeidler, Sadler, Simmons, & Howes, 2005). This is what Zeidler (2014) refers to as "SSI as curriculum emphasis", because SSI start from the assumption that as part of scientific literacy, students must understand the social, therefore ethical, political and economic dimensions of scientific activity (Zeidler, 2014). SSI is different because in addition to addressing the conceptual and procedural aspects of scientific knowledge, it emphasizes what is known as epistemic knowledge, and in particular the ethical aspects of science (Fowler, Zeidler, & Sadler, 2009; Zeidler et al., 2011, 2005). As stated by Melville et al. (2007): "Unique to SSI, when compared to other frameworks connecting science and society, is its emphasis on students’ psychological and epistemological development, as well as on the development of character and virtue that burgeons as students grapple with the ethical implications of their decisions" (Kahn & Zeidler, 2019, p. 608).
More recently, other authors have brought teaching SSI in formal science education further, seeing it as a way to help students develop a scientific literacy that allows them to exercise an active and conscious citizenship (Ariza, Abril, Quesada, & Garcia, 2014; Barrue & Albe, 2013; Hofstein, Eilks, & Bybee, 2011; Kolsto, 2001; Sadler & Zeidler, 2009). However, seeing that each country develops its own science curriculum, the reflection about the changes in the curriculum from the SSI perspective is localised and different depending on the country. For this reason, in order to define this interpretation of SSI at a conceptual level, common constructs in science education research have been used, which are shared among the academic community and can be identified in curricula. These are the following: Nature of Science (NoS), Socioscientific Reasoning (SSR), and argumentation.

3.1.1. Nature of Science (NoS)

Nature of Science (NoS) can be understood as a reflection about the very act of doing science (Jenkins, 2009). The discussion about the NoS tries to describe and understand the process of creating scientific knowledge (Acevedo-Díaz & García-Carmona, 2016; Jenkins, 2009). It came to widespread use in the second half of the 20th century as a result of a process of research in the area of history and philosophy of science, focusing on how science works (Sancho & Lopez Sancho, 2002).

NoS has been understood as an objective of science education aiming to teach students a meta-knowledge about science, i.e. how scientific activity is performed (Vázquez-Alonso & Manassero Mas, 2017). Other authors have referred to it as Ideas about Science (IaS) (Bartholomew, Osborne, & Ratcliffe, 2004; Ratcliffe & Millar, 2009). In other words, NoS is seen as one of the two main components of scientific knowledge, the other component being facts and principles of science (Bennássar et al., 2010). Some scientific literacy frameworks divide scientific knowledge into conceptual, procedural and epistemic. NoS has been called the "epistemology of scientific knowledge as well as the processes/methods used to develop such knowledge" (Zeidler, Sadler, Simmons, & Howes, 2005, p.358).

As any student learning outcome, Nature of Science has been evaluated throughout the years according to these visions, mostly quantitatively via questionnaires (Laugksch, 2000). These tools also constitute operationalisations of the term. In the last years, authors agree about the Views on the Nature of Science (VNOS) questionnaire by Lederman (Acevedo-Díaz & García-Carmona, 2016). It includes the following dimensions: 1) Definition of science and
technology, 2) Interactions between science, technology and society, 3) Influence of society in science and technology, 4) Influence of science and technology in society, 5) Internal sociology of science, and 6) Epistemology.

More recently, the need to teach about the NoS as part of basic science education increased as RRI started to reach public policy and scientific practice (Bayram-Jacobs, 2016; de Vocht, Laherto, & Parchmann, 2017; Heras & Ruíz-Mallén, 2017; Lundström et al., 2017). In particular, the changes brought about with the RRI vision have been said to trigger a reflection on how we know what we know, and the effects of that knowledge, i.e. its social impact (Sherborne, 2014). This is one of the key dimensions of the NoS.

3.1.2. Socioscientific Reasoning (SSR)

The construct Socioscientific Reasoning (SSR) was put forward as a genuine subset of skills that enable students to become responsible citizens (Sadler et al., 2007b). Scholars who propose this construct start from the assumption that SSI are an inherent part of scientific activity, therefore students should have the skills to manage them as part of their science education. However, they believe that the specifications of scientific literacy do not sufficiently cover these skills but that other, more specific constructs are needed, therefore pushing the reconsideration of the science curriculum. SSR, as initially proposed, had four dimensions, namely (Zeidler et al., 2019):

1) Complexity: perceiving and reasoning through the complexity of SSI
2) Perspective taking: analysing an issue from the perspective of the different people involved in it
3) Inquiry: identifying the information that is yet to be found out about the issue, as well as a strategy to find it
4) Scepticism: being able to recognise where information about an SSI or solutions to it may be biased

Later, another dimension was added, namely 5) Affordances and limitations of science. It describes the ability to recognise to what extent available scientific knowledge is sufficient to comprehend the issue, and to identify aspects of the issue that science cannot address.

Building on the operationalization of these learning goals, work has been devoted to develop instruments that measure student achievement of the skills associated to dealing with SSI.
One of these tools is the questionnaire known as the Quantitative Assessment of Socio-Scientific Reasonings or QuASSR. The questionnaire assesses SSR, and the understanding of the specific issue that students are learning, for example, fracking (Romine et al., 2017).

3.1.3. Argumentation

Argumentation is the last of the three most common constructs that have been used to represent the need to renew the science curriculum so that students are able to deal with SSI (Dawson & Venville, 2010; Evagorou et al., 2012; Evagorou & Osborne, 2013; Lin & Mintzes, 2010; Shea, Duncan, & Stephenson, 2014). According to authors, argumentation is a useful skill in the process of understanding and making decisions about scientific issues. Some authors consider argumentation a Higher Order Thinking Skill or HOTS (Evagorou, Jimenez-Aleixandre & Osborne, 2012; Garrido Espeja & Couso Lagarón, 2015; Tal & Kedmi, 2006; Zeidler & Nichols, 2009). In fact, if the three constructs that are reviewed in this subsection, argumentation is the most transversal to all STEM subjects. For example, it has been considered as crucial in how students develop their understanding of mathematics content (Diez-Palomar, Chan, Clarke, & Padrós, 2021; Diez Palomar, 2017).

Research on argumentation in science education has been led by Osborne and others. Skills such as using evidence to justify positions and to engage rationally in oppositional discourse have proven to be essential in developing students’ scientific argumentation (Evagorou & Osborne, 2013; Simon, Osborne and Erduran, 2003). These are very similar principles as those described in the SSR framework. An interest is also identified among scholars to determine to what extent argumentation about SSI, or socio-scientific argumentation, is different from scientific argumentation. One of the most clarifying positions regarding this matter is from Victor Sampson, who establishes differences between the two types of argumentation based on the types of arguments considered, as well as the nature of the supports and challenges to the claims (Sampson, Simon, Amos, & Evagorou, 2011).

3.2. SSI-based instruction

The theoretical work carried out regarding how to adapt the science curriculum to the need to help students deal with SSI runs in parallel and in relation to another way to conceptualise the application of SSI to formal education. Such conceptualisation can be described as the
pedagogical application of SSI, where SSI are used as means to teach the science curriculum. In other words, it focusses on the application of SSI in the classroom, in the actual context of a lesson.

The literature that follows this understanding of SSI in formal education deploys terms such as Socioscientific Issues based instruction, SSI-based instruction (Sadler et al., 2016) or SSI based instruction (Davut Gul & Akcay, 2020), issue-based instruction (Zangori et al., 2018), SSI-based education (Presley et al., 2013) or even SSI-based science education (Irez et al., 2017). The term SSI-based instruction, however, is gathering most consensus and used in the most recent publications.

In this instrumental understanding of SSI in education, SSI constitute a way to reflect and renew the components of the act of learning in a classroom, so that they respond better to students' needs and thus lead to better learning, for example in terms of student achievement, engagement, efficiency of the teaching and learning process. Therefore, the publications belonging to this conceptualisation of SSI in education are devoted to determine how the components of a teaching and learning experience must be, from the point of view of SSI.

### 3.2.1. Frameworks for SSI-based instruction

Some of the efforts to determine how the components of a teaching and learning experience must be from the point of view of SSI aim to defining comprehensive frameworks. To that goal, position papers, literature reviews and expert consultation have been used. For example, as a result of a Delphi study, Irez et al. developed a framework for teaching and learning SSI including 6 dimensions: 1) Learning outcomes, 2) Domains, 3) Pedagogical strategies, 4) Features of Learning environment, 5) Nature of instructional materials & sources, and 6) Assessment (2017). Each dimension contains categories that operationalise it in more detail. For instance, dimension 1) Learning outcomes includes a list of 18 items describing aims and learning outcomes in an SSI-based science education scenario, such as develop scientific thinking skills, develop scientific argumentation skills, develop decision making skills, develop moral reasoning skills, and understand the relationship between Science, Technology, Society and Environment, among others.

Other frameworks that conceptualise SSI-based instruction in the literature rather focus in one or a few of the aspects contemplated in the comprehensive ones. Dr. Troy Sadler, in collaboration with other scholars, has carried out the most systematic work in this direction.
As a result, an SSI-based teaching and learning framework is available and has been used in science education and research for the design and the analysis of this educational practice (Sadler & Murakami, 2014). The framework was built on the basis of real educational experiences with SSI that had been reported in educational research (Presley et al., 2013). Since then, it has been reviewed and refined.

This framework is formed by three concentric circles, which contain the core aspects in the first circle. The core aspects of the framework conceive SSI-based teaching as composed by three dimensions, namely 1) Design elements, 2) Learner experiences, and 3) Teacher attributes. The design elements operationalize what an SSI-based teaching and learning experience must be from the point of view of those who design it. It includes guidelines, such as that the instruction is built around a compelling issue, provides scaffolding for higher order practices, and uses technology to facilitate learning, among others. The learner experiences specify the processes that learners are engaged in when participating in SSI-based teaching and learning. These include confronting scientific ideas related to the issue, collecting and analysing scientific data related to the issue and confronting the ethical dimensions of the issue, among others. Finally, the definition of the core aspects of SSI-based teaching and learning from the perspective of teacher attributes defines what teachers must be able to do in one of these experiences. These include being knowledgeable about the science content related to the issue, as well as of the social considerations associated to the issue, in addition to having a position where they are not a knowledge authority.

Figure 5: Graphic representation of the framework of SSI-based teaching and learning (Sadler and Murakami, 2014)
This three-dimensional core aspects of the framework are embedded in two other circles: first, the classroom environment, which refers to "ways in which the classroom environment defines and influences enactment of the core aspects" (Sadler & Murakami, 2014, p. 339). For example, the authors consider that a collaborative and interactive classroom environment contributes to a successful implementation of SSI. The last concentric circle is the peripheral influences, which refer to aspects of formal education that go beyond the classroom but yet influence the act of teaching and learning, such as the school environment or the regional and national educational context.

3.2.2. Models for SSI-based instruction

In the last years, work has been devoted to operationalising what students' actual learning experience is like in an SSI-based instruction scenario. The work in this direction starts from the assumption that a key component of didactics in general and thus, didactics of science, is the teaching methodology. Teaching methodologies are ways to facilitate student learning, which mediate between the content, the students and the teacher (Mallart, 2012). However, SSI is not a teaching method as such. In order to apply it pedagogically, it involves modelling the learning sequence (Domènech-Casal, 2017). Because of its similarities with existing practices such as context-based learning, a debate is open in academia about the existence of what is called instrumental or pedagogical application of SSI as a stand-alone educational practice. To that goal genuine SSI-based teaching practices have been empirically validated through systematic research (Owens et al., 2019).

The most common pedagogical application of SSI to a learning sequence uses the principles of Inquiry-Based Learning, also known as IBL (Albe et al., 2014). IBL involves students finding information to answer a question in a systematic, empirical, scientific way (Constantinou, Tsivitanidou, & Rybska, 2018). IBL has been used in different educational levels including primary, secondary and higher education, and for different purposes. As noted by Minner, Levy and Century (2010), Inquiry-Based Learning (IBL) has been researched for decades. The authors highlight the “essential features of classroom inquiry by the National Research Council in the USA:

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
• Learners formulate explanations from evidence to address scientifically oriented questions.
• Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
• Learners communicate and justify their proposed explanations.

While sharing similar principles, authors proposed different models for students to engage in IBL. As a result of a systematic literature review, Pedaste et al. (2015) propose a synthetic framework for Inquiry-Based Learning.

![Figure 6: A five-stage model for Inquiry-Based Learning (Pedaste et al., 2015)](image)

Specifically, due to its similarities with the scientific process, IBL has been applied in science education as Inquiry-Based Science Education (IBSE). As it is the case for IBL, several models have been proposed in the literature for Inquiry-Based Science Education. One of
the most used models for IBSE is that of the 5E’s (Bybee, 2000). It includes the following phases:

1. Engagement: The teacher or a curriculum task assesses the learners’ prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students’ thinking toward the learning outcomes of current activities.

2. Exploration: Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.

3. Explanation: The explanation phase focuses students’ attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviours. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.

4. Elaboration: Teachers challenge and extend students’ conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.

5. Evaluation: The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

On the basis of the IBL and IBSE models, specific proposals are available for teaching and learning SSI through inquiry. The following subsections review the main ones.

3.2.2.1. The SSI-TL model

The Socioscientific Teaching and Learning (SSI-TL) model was proposed by American science education researchers, under the leadership of Troy Sadler, who is one of the most
prolific authors in the field of SSI and SSI education (Troy D. Sadler et al., 2017). The model is grounded on the premise that one of the characteristics of SSI is that they have links to scientific knowledge. For this reason it is common to see SSI as contexts to teach scientific content (Klosterman & Sadler, 2010; Troy D. Sadler et al., 2016). In some of these cases, SSI are conceived as a tool to "lower down" scientific knowledge from the abstract to the concrete, so that it is easier for students to learn: “SSI are easily recognised by students as real-world scenarios related to contemporary issues, thus bringing a sense of authenticity and relevance to the science classroom” (Romero-Ariza et al., 2017a, p. 33). SSI have also been used to teach content knowledge and SSR in a single learning experience (see Eggert, Nitsch, Boone, Nückles, & Bögeholz, 2017); decision-making (Wu, 2007); moral sensitivity (Fowler et al., 2009); NoS (Eastwood et al., 2012; Rola, 2014; Troy D. Sadler et al., 2007); and communication skills (Chung, Yoo, Kim, Lee, & Zeidler, 2016).

Figure 7: The SSI-TL model, from Sadler et al. (2017)
The model is presented as a way to make progress towards bringing SSI into learning environments. In other words, the model draws on principles from other teaching and learning approaches such as project-based learning, context-based learning, and what the author refers to as case-based approaches. Although the model also includes students’ learning objectives, its main contribution to the operationalisation of the pedagogical application of SSI in teaching and learning is the learning sequence that it proposes. Such sequence is composed by three phases, namely 1) Encounter focal issue, 2) Participate in the main teaching and learning experience, and 3) Synthesise ideas and practices. In the first phase, students become acquainted with the SSI. In the second phase, students engage with a set of processes where they consider the issue as complex, analyse it from different perspectives, they spot what parts of it are still to inquiry about, they analyse information about it sceptically, and they consider the limitations of science. In the third and last phase, students compare their initial knowledge about the issue with the knowledge they gained.

3.2.2.2. The SSIBL model

Socio-Scientific Inquiry-Based Learning (SSIBL) was proposed as a teaching model to specifically achieve the learning goals of RRI policy in formal science education (Amos, Knippels, & Levinson, 2020; Romero-Ariza et al., 2017). It combines Inquiry-Based Learning (IBL), Socio-Scientific Issues (SSI) and Citizenship Education (CE). The model addresses three principles. First, authenticity, understood as framing scientific content in a scenario that is relevant to students, calls for action, and it has a component of controversy. The second principle is mapping controversy, which refers to understanding opposed sides of a fact from different perspectives such as risk vs benefit or ethical principles. This principle could be the most genuine to RRI as it responds to both the processes and the aims of RRI. Finally, SSIBL teaches students to take action (Romero Ariza, Abril, Quesada, & Garcia, 2014).

In practical terms, SSIBL is a three step model. The first step is contextualisation, where students get in contact with the SSI. This step may take one lesson. The next step is de-contextualisation, where students learn the content or skills out of the context of the SSI. This step may take between one and three lessons. Finally, the step known as re-contextualisation involves going back to the SSI for decision making and argumentation. This last step takes about one lesson (Christenson, Chang Rundgren, & Zeidler, 2014). The model was tested with preservice teachers in Spain (Quesada, Romero-Ariza, & Abril, 2017).
3.2.2.3. The model for ethical Inquiry into Socioscientific Issues

The pedagogical model for Ethical Inquiry into Socioscientific Issues in science was introduced as a way to help teachers introduce SSI in their teaching (Saunders & Rennie, 2013). It is based on the principles of ethical thinking, as a way to approach students' decision-making about the SSI. In particular, the authors use pluralism as a way to cater for the diversity of identities that are present in our society, based on gender, culture, ethnicity or religion. On this basis, the authors propose an 8-step model where students engage with the broad issue, then they investigate the science behind the issue, and then they reflect individually. After that, a group discussion takes place and the students decide on the specific question that will be addressed about the SSI. The main part of the activity is to apply pluralist ethical thinking onto the issue, which leads to students ethical decision making and justification. Finally, evaluation and reflection on what has been learnt takes place. This process is outlined in figure 9 below.
Figure 9: Model for ethical thinking about an SSI, as part of the "model for ethical inquiry into scientific issues. Adapted from Saunders and Rennie (2013)
4. The science teacher as a professional

The pedagogical application of SSI is an educational practice, and it is carried out by teachers. As shown in earlier sections of this theoretical framework, teachers are a key component in SSI-mediated teaching and learning experiences to the extent that their actions, skills and beliefs will influence how students experience SSI in the classroom (Karisan & Zeidler, 2017).

However, teachers are not used to SSI teaching because they were not trained in this model (Gray & Bryce, 2006). SSI is new for science teachers, whose job has been traditionally discipline and content-based, therefore leading to a predominantly teacher-led instruction (Ekberg et al., 2013; Tidemand & Nielsen, 2017). Therefore, in order to understand SSI-based instruction as an educational practice, it is useful to review the science teacher professional profile.

4.1. Science teaching competences

In most educational systems nowadays, the science teacher professional profile is specified in terms of competences. Competences are a transversal way to determine the teaching profile, which is organised by dimensions or big axes, to which knowledge, skills and attitudes contribute (European Commission, 2013; Martínez & Farró, 2012). In Europe, these competences are determined at a National or regional level, and thus they may be very different. In terms of terminology, some frameworks use "competence" and others "competency", or a combination of both. For clarity purposes, this study follows the work by Mulder. The author states that competence is a comprehensive concept for abilities or capabilities of people or organisations, while a specific competency forms a part of competence" (Roelofs & Sanders, 2007).

Teaching competences describe the performance that is expected from teaching practice, as a way to describe behaviour: "Complex combinations of knowledge, skills, understanding, values, attitudes and desire, leading to effective action in situation in a particular domain" (Deakin Crick, 2008, quoted in Caena, 2014). In the case of teachers, a distinction has been made between teaching competences and teacher competences (Caena, 2011), also in EC (2013) & OECD (2009). Whereas the first emphasizes the act of teaching, the second follows a systemic view of the teaching profession, which takes into account other dimensions
outside classroom practice such as the school and the community (Martínez-Izaguirre, Álvarez de Eulate, & Villardón-Gallego, 2017).

There is no specific framework for secondary school science teaching competences at a European level, as opposed to other areas such as digital competence (Redecker & Punie, 2017). The only competences highlighted as important in general teacher competence frameworks are: "a specialist knowledge of the subject(s) they teach, plus the necessary pedagogical skills to teach them, including teaching to heterogeneous classes, making effective use of ICT, and helping pupils to acquire transversal competences" (European Commission, 2013).

The most precise National level teacher competence frameworks in Europe are from the United Kingdom (UK) and the Netherlands. The Dutch frameworks provide a three-level description for each of the seven key teacher competences (European Commission, 2013). In the UK, teachers must:

1. Set high expectations which inspire, motivate and challenge pupils
2. Promote good progress and outcomes by pupils
3. Demonstrate good subject and curriculum knowledge
4. Plan and teach well structured lessons
5. Adapt teaching to respond to the strengths and needs of all pupils
6. Make accurate and productive use of assessment
7. Manage behaviour effectively to ensure a good and safe learning environment
8. Fulfil wider professional responsibilities

4.1.2. Science teaching competences in Spain

In Spain, secondary school science teachers are qualified to teach science related subjects, as in: Biology, Geology, Physics, and Chemistry. They can also teach general natural science, technology or mathematics depending on the educational level, regional regulations and the type of school. Efforts have been invested in defining teacher professional competence, mostly in initial teacher education (EC, 2013). The most representative result is the general teacher competence framework developed by the National Agency for Assessment and Certification of Education (ANECA) in 2004 (Martínez-Izaguirre et al., 2017). This work, which was developed as a result of proposals from different universities, was translated into policy in 2006 (Ministry of Education and Science, 2007a, 2007b). The current secondary
school teacher competences are regulated by policy at least for initial teacher education. Following the political organisation of the Spanish state, all autonomous regions further develop this policy.

In 2010, the reform of initial secondary school teacher training from a six months long course to a European certified Masters’ degree led to greater systematization of teacher competences in Spain (Benarroch, Cepero, & Perales, 2013; Guisasola et al., 2013). There are different specializations in the masters', according to the subjects that the teacher will be able to teach at secondary school: language, arts, sciences, etc. Within the prerequisites to enrol in this master's is an undergraduate degree in a discipline related to the Masters' specialisation (Ministry of Education and Science, 2006). This masters' programme constitutes initial secondary school teacher education and it is regulated by the Spanish law Act Real Decreto 1834/2008, of 8 of November (Ministry of Education and Science, 2008), which was modified by the Act Real Decreto 665/2015, of 17 of July (Ministry of Education Culture and Sports, 2015). This law is further developed by the Orden ECI/3858/2007, of 27 of December, which lists the following content for initial secondary school teacher education:

- General module (12 ECTS):
  - Learning and personality development
  - Educational processes and contexts
  - Society, family, and education
- Specific module (24 ECTS):
  - Disciplinary training complements
  - Learning and teaching the disciplinary subjects
  - Teaching innovation and initiation to educational research
- Professional practice module (16 ECTS):
  - Practice in the specialisation, including master thesis

In the specific case of science teachers, a discussion is open that calls for renewing their professional competences in the light of recent developments towards the science and technology ruled society. One way to develop a teacher competence framework is by involving developers and selected key teachers (Roelofs & Sanders, 2007). This is the methodology followed by Benarroch, Cepero et al. (2013), who enhanced the competences cited in the Spanish law with results of Spanish success cases reported in the literature, to propose a science teachers' competence framework based on six axes, namely: 1) Knowledge
about the theoretical and practical developments of teaching and learning the subject, 2) Transform the curriculum in programmes, 3) Develop criteria to select and create educational materials, 4) Promote a climate that facilitates learning and values students’ contributions, 5) Know assessment techniques and strategies and understand assessment as a tool for regulation and stimulate effort, 6) Facilitate teaching and learning processes that use ICT tools. The main contribution from this framework is to include Media and ICT. Additionally, the authors stress the need to have student needs and role in mind.

Perales-Palacios et al. (2014) draw on multiple sources to elaborate a competence framework for science teachers, including the science curriculum of secondary education, student learning goals as stated in the PISA test, opinions from in-service teachers, a literature review on epistemic conceptions of teachers, theoretical frameworks of teacher competences, and social needs, in particular science in the media. On this basis, they propose a set of fifteen (15) competencies, structured in three main domains, namely: 1) Complements to disciplinary training, 2) Teaching and learning of subjects, and 3) Educational innovation and introduction to educational research. The first domain is composed by four competences, which including the curricular content that students must learn, as well as the rationale behind teaching such curriculum. It also includes knowledge about the history of science and its recent developments, as well as the practical contexts or situations in which curricular content is applied. The second domain is composed by six competences, which are the same as the framework by Benarroch et al. presented above. The third domain is composed by five competences, which mainly refer to critically analyse educational practice in order to identify problems and propose solutions.

The framework that these authors propose put a strong focus in a view of science consistent with the new developments of scientific competence. In particular, it emphasizes aspects of the Nature of Science such as the nature of scientific knowledge, how it is created, etc. It even includes these contents in the module about disciplinary knowledge, not only in the knowledge related to what students have to learn.

4.1.3. Conclusions about secondary school science teaching competences nowadays

The analysis of the literature regarding competence frameworks for secondary school science teaching allows to draw certain conclusions. In general terms, it can be observed that the
frameworks are not divided into teacher knowledge, skills and attitudes or dispositions. Instead, they are divided into domains. These normally cover mainly three domains, namely C1) disciplinary, C2) didactic, and C3) educational innovation and Professional Development (PD).

Domain D1) is concerned with the command of what is known as content knowledge, or knowledge about the discipline, such as mathematics, languages, or in this case, science. In secondary school, in Spain the science discipline is divided into two specialities in secondary school, namely Biology and Geology, and Physics and Chemistry. According to the literature reviewed, the societal impact of science and the applications of scientific knowledge to daily life are not necessarily contemplated in initial science teacher education in Spain but are an important part of science teachers' education.

Because of its close link with the discipline, domain D1 is known as disciplinary. However, this dimension is not the same as the body of knowledge that teachers must have in order to access the teaching profession. The body of knowledge needed for science teaching in secondary school is specified and developed in an undergraduate degree in one of the subjects of their pedagogical speciality. For example, a secondary school Physics teacher in Spain has an undergraduate degree in Physics (or similar), this is their SMK. However, the disciplinary dimension of science teaching competences is concerned just with the fraction of such knowledge that is relevant for the teaching profession, in this case to secondary school level. Consistently, science teaching competence frameworks refer to learners' competences, seeing that as part of the teaching profession, teachers must be able to help students develop a set of competences (knowledge, skills and attitudes). Finally, this domain describes the need to be aware about the current state and changes in educational policy regarding the goals of science education from the point of view of student achievement.

Domain D2) is concerned with the pedagogical dimension of science teachers' profession. This domain often includes competences known as transforming the curriculum into teaching and learning activities that allow students to develop the competences and achieve the learning goals of the curriculum. This domain includes taking into account the characteristics of the receivers of these activities, this is, students. This indicator also describes teachers' ability to deal with student learning as part of a broader environment that has been referred to as "ambient" of learning, this is, the characteristics of formal science education. Some authors describe include as part of this ambient the organisational aspects
of the school, which has been called grammar of schooling (Martínez Arbeiaiz & Correa Gorospe, 2009; Mehta & Datnow, 2020). It also comprises the ability to design and implement effective assessment techniques that allow students to regulate their learning and the teacher to collect useful information about their progress.

Finally, domain D3) emphasizes reflective practice as a way to improve teaching and the teaching profession. It includes teachers' ability to define questions to further investigate regarding their practice, with the objective to improve it.

### 4.2. Science teachers' knowledge

Teacher knowledge is a construct describing “ideas derived through a teachers’ practical experience and formal schooling” (Calderhead, 1996, quoted in Van Driel et al., 2013, p. 848). Teacher knowledge is one of the most used theoretical constructs in the study of teachers and the teaching profession in particular, for the past half a century, along with other constructs such as personality traits, behaviour, or thinking (Roelofs & Sanders, 2007; Van Driel, Berry & Meirink, 2013). This accumulated knowledge helps to ground better the competence frameworks described above, together with skills and attitudes.

The construct of teacher knowledge is grounded in a division between two concepts, namely knowledge and beliefs. Despite the fact that the boundaries between the two concepts have been openly recognised to be unclear in the literature and even used indistinctively (Abell, 2007), a main distinction can be made. Whereas teacher knowledge is built and developed through experience (van Driel, Verloop & de Vos, 1998), beliefs are part of a deeper layer that is related to values and attitudes that affect other domains than just their work. For an extensive review of the topic, the reader shall refer to Gail Jones & Leagon (2013).

Teacher knowledge has been discussed for years since Lee S. Shulman put it forward, thus resulting in different approaches. For example, during its first years as a construct, it was conceived as knowledge "for" teachers, this is, some sort of advice on how to teach, especially for making students perform in standardized tests (Zeichner & Liu, 2010). However, since the 80s, when constructivist learning approaches became popular, it switched to knowledge "of" teachers (Barendsen & Henze, 2019; J. H. van Driel et al., 2013).
4.2.1. Types of teacher knowledge

After a few years of research in teacher knowledge, judging from recent literature, there is a consensus in two main types of teacher knowledge, namely Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK) (Albe et al., 2014; Park, Jang, Chen, & Jung, 2010).

![Synthesis of Models for teacher knowledge](image)

Figure 10: Synthesis of Models for teacher knowledge. Adapted from van Driel et al. (2013)

4.2.1.1. Subject Matter Knowledge (SMK)

A very clear separation seems to exist between what is known as "Subject Matter Knowledge" or SMK and other types of teacher knowledge. Sometimes referred to as disciplinary knowledge, it includes the academic, content knowledge of the discipline that they are teaching. For this reason, SMK has been considered as a prerequisite to teachers' being able to teach the content to students (J. H. van Driel et al., 1998). Science teachers' SMK has a much longer and more systematic body of literature than other types of teacher knowledge (Abell, 2007). Indeed, SMK has proven to be the most assessable domain of teacher knowledge to date (Smith & Banilower, 2015). As shown in the previous section, the curriculum of some secondary school teachers' initial education programmes include SMK, for example in the modules that are called "Disciplinary training complements".

4.2.1.2. Pedagogical Content Knowledge (PCK)

Another well-established type of teacher knowledge in the literature is Pedagogical Content Knowledge (PCK). Its promoters suggest that there is a genuine body of knowledge that teachers have, which is directly related to how they develop their instruction. PCK makes a
difference between three elements for successful teaching: 1) the knowledge about the content to be taught, which is similar but not exactly the same as SMK. This is the knowledge that students should end up having. This is called "Content Knowledge"; 2) the way to teach such content, pedagogy, the knowledge about didactics, how to teach, what it means to be learning and so on, that are intimately linked to any job related to helping someone else to learn. This is called "Pedagogical Knowledge". 3) Knowledge of context, which refers to the educational setting: students, school, etc.

According to Shulman, in the intersection of these two components lays a new, genuine characteristic of teaching practice called "Pedagogical Content Knowledge", which refers to the ability to teach a particular knowledge to a particular group of students (Shulman, 1986). Some authors consider that PCK acquires different forms depending the discipline, especially in science teaching, or even particular topics within a discipline. For example, it is now known what type of PCK is necessary for better instruction regarding the solar system (Henze, van Driel, & Verloop, 2008a). PCK is part of teacher competence frameworks such as the competences for teaching from the European Commission (European Commission, 2013).

As most constructs, PCK is also subject to a fair amount of discussion. Scholars point out that there is no solid agreement in the community that makes it easy to build on the concept (Berry, Loughran, & van Driel, 2008; Borowski et al., 2012). For some authors, the main issue with PCK as a research construct is the lack of a common definition that can be operationalized for assessment (Smith & Banilower, 2015). Van Driel et al. (2013) review the theoretical models available about teacher knowledge and they point out how scholars have proposed evolutions of the model. These models normally include categories further detailing the existing ones, for example: Pedagogical Process Knowledge (PPK) (Smith, C.,
Blake, A., Fearghal, K., Gray, P. & McKie, 2013). However, compartmenting the teacher knowledge construct has been strongly criticised (Abell, 2007).

![Diagram of Pedagogical Content Knowledge](image)

Figure 12: Components of Pedagogical Content Knowledge for science teaching. Source: (Magnusson, Krajcik, & Borko, 1999)

Some scholars have made an effort to synthesize different proposals for PCK. One of the most clarifying is the distinction between transformative and integrative PCK (Borowski et al., 2012). Essentially, a transformative approach to PCK conceives it as an independent construct from other types of teacher knowledge, such as SMK or general pedagogical knowledge. In this approach, PCK is an entity with its own dimensions and components. Teachers can have academic knowledge of content, pedagogical knowledge (such as how to manage the roles of students in the classroom), and they may be able to gather information from students, such as their previous knowledge or misconceptions. According to the authors supporting the transformative understanding of PCK, that knowledge coexists with the knowledge that exists within PCK, which is where all these knowledge bases are integrated for teaching a specific content (Magnusson et al., 1999).
Research under this assumption studies PCK components separately and mainly the consistency between them as indicators of good teaching practice.

Integrative PCK, on the contrary, defines PCK as a combination of other elements that the transformational model considers external to it. It includes SMK, pedagogical knowledge (PK), and students' knowledge of SMK which is known as Knowledge of Content (KoC) (Abell, 2007).

![Figure 13: Graphic representation of the integrative approach to PCK, where PCK is the asterisk where the three circles overlap. Source: Gess-Newsome, 1999)](image)

Park and Oliver's hexagonal model of PCK follows an integrative approach, with six interconnected components, namely 1) Knowledge of Science curriculum, 2) Knowledge of students' understanding of Science, 3) Teacher efficacy, 4) Knowledge of instructional strategies to teach Science, 5) Knowledge of assessment of Science learning, and 6) Orientation to teaching Science (Park & Oliver, 2008).

4.2.2. Teacher knowledge as a tool to characterise teaching practice

In addition to a way to ground the specifications of science teachers' professional profile, for example in terms of competences, teacher knowledge has been used to research teaching practice and in particular in the context of educational innovation, reform, or change (Henze, Driel, & Verloop, 2007; Park et al., 2010; J. H. van Driel et al., 2013). Teacher knowledge has been seen as "a relevant source for innovators when implementing educational changes" (van Driel, Beijaard, & Verloop, 2001, p. 141). More specifically, teacher knowledge is
frequently used to predict teachers' actual practice in the classroom (Barendsen & Henze, 2019; Gail Jones & Carter, 2007).

In the specific case of SSI, the importance of teacher knowledge has been stressed. For example, when discussing how to teach moral reasoning, Norman Lederman already expressed concerns about teachers having sufficient knowledge to carry out SSI instruction among the two main factors for its success (Zeidler & Keefer, 2003). For this reason, research measuring and characterising science teachers' PCK for SSI-based instruction is developing. It is common that these investigations are grounded on the assumption that stronger PCK it is assumed to contribute to deliver better quality of instruction than weaker PCK (Bayram-Jacobs et al., 2019).
5. A framework to analyse SSI-based instruction

As a result of the review of the literature performed in previous sections, it was found that SSI-based instruction is a new teaching practice, which is still under development and conceptualisation. On this basis, and using the concepts that have been reviewed above, SSI-based instruction is defined in this investigation as a teaching practice where students learn about an SSI, and in the process of learning they may learn or draw on existing scientific knowledge, skills and attitudes. This phenomenon is examined through the lens of educational innovation, this is, as a practice that teachers carry out as a way to tackle one of the challenges that formal secondary education is facing, which is to bridge the gap between an obsolete, abstract and content-centred science curriculum and a reality where science and technology are more present than ever in our lives.

In order to approach this reality, a reference framework has been developed to analyse SSI-based instruction, which is based on the concepts reviewed in previous sections. More specifically, three different dimensions of SSI-based instruction have been determined and provide a reference framework of this investigation. The proposed dimensions are the following:

- D1) Objectives of SSI-based instruction
- D2) Components of SSI-based instruction
- D3) Resistance to SSI-based instruction

This three-dimensional model follows previous, empirical attempts to analyse innovations in secondary school teachers' professional practice, and is based on the revision of the literature previously performed in this chapter. Therefore, it represents well the range and variety of interpretations of teachers delivering SSI-based instruction. The framework is holistic in its understanding of the phenomenon and is considered as an adequate attempt to analyse SSI-based instruction as an educational innovation in secondary school. These dimensions, as well as their categories and sub-categories, are explained in detail in the sub-headings below. The categories and sub-categories in each dimension are a synthesis of previous, empirical attempts to study the phenomenon and that are reported in educational research publications.
5.1. Dimension 1) Objectives of SSI-based instruction

This dimension analyses the contributions of SSI-based instruction as a means of achieving the goals of formal science education. SSI-based instruction has been seen as a useful way of achieving certain goals in science education, but there is a lack of understanding about how teachers pursue them in practice. To what extent teachers share this view is essential to understanding how students experience SSI-based instruction, and provide support for teachers where needed.

Formal education, to the extent that it contributes to equipping citizens to navigate and contribute to society, is in constant renewal. According to the literature reviewed, SSI-based instruction promotes in particular the following objectives of science education: a) to contribute to developing scientific literacy, b) to teach scientific knowledge and c) to convey the interdisciplinarity of knowledge. The definitions of these components are explained below.

5.1.1. Contribute to the development of scientific literacy

There is a consensus that SSI-based instruction has been seen as a way to contribute to students' development of what is known as scientific literacy or scientific competence. However, earlier in this dissertation, the culturally constructed nature of scientific literacy has been discussed, showing its different operationalisations. As a result, two main views were identified: scientific literacy for scientists and scientific literacy for citizens. SSI-based instruction contributes to scientific literacy for citizens (Zeidler et al., 2019). This view expresses the need for students to develop a level of scientific literacy that allows them to be active, responsible and conscious citizens (Díaz-Moreno et al., 2019; Hofstein et al., 2011; Zeidler & Nichols, 2009).

One framework reflecting scientific competence for citizens is PISA 2018 Scientific literacy (Organisation for Economic Co-operation and Development, 2019). The competencies determined as part of scientific literacy are very similar to that of the national curriculum in Spain and other European countries. Accordingly, the contributions of SSI-based instruction to the three scientific competences have been analysed: 1) Explaining phenomena scientifically; 2) Evaluating and designing scientific enquiry; 3) Interpreting data and evidence scientifically.
5.1.1.1. Explaining phenomena scientifically

This sub-category analyses teachers' delivery of SSI-based instruction as a way to contribute to developing students' competence formulated as Explaining phenomena scientifically. This competence “Recognising, offering and evaluating explanations for a range of natural and technological phenomena” (Organisation for Economic Co-operation and Development, 2019), p. 104.

5.1.1.2. Evaluating and designing scientific enquiry

This sub-category is concerned with how teachers practice SSI-based instruction, with the objective to contribute to the development of the competence known as Evaluating and designing scientific enquiry. This competence is defined as “Describing and appraising scientific investigations and proposing ways of addressing questions scientifically” (Organisation for Economic Co-operation and Development, 2019), p. 104.

5.1.1.3. Interpreting data and evidence scientifically

This sub-category analyses teachers' implementation of SSI-based instruction as a way to contribute to students' development of the competence "Interpreting data and evidence scientifically". This competence is described as “Analysing and evaluating scientific data, claims and arguments in a variety of representations and drawing appropriate conclusions” (Organisation for Economic Co-operation and Development, 2019) p. 105.

5.1.2. Teach scientific knowledge

Helping students develop scientific knowledge is another objective of science education. Scientific knowledge is curricular content that contributes to student development of scientific competence (Organisation for Economic Co-operation and Development, 2019). Like scientific competence, curricular content is localised and therefore different depending on the country.

As has been presented in Chapter 2: Theoretical framework, there are different conceptualisations of scientific knowledge, often associated with scientific facts and principles. However, recent changes in national curricula and international assessment tests reflect the purpose of science education as promoting a science, technology and innovation-guided society. This means complementing the development of content knowledge with
other types of knowledge relate to scientific inquiry, and a reflection on the nature of scientific activity. However, it has been proven that in countries where these aspects are supported or not in the curriculum, they are not implemented. This is attributed to the difficulties associated with educational practice change. In this sense, SSI-based instruction has been seen as a good way to bridge the gap between the curriculum and classroom practice, to convey aspects of the content as well as start introducing knowledge to science classes that is not so certain, under study, or worth discussing from other points of view that are not strictly scientific. Therefore, it is necessary to evaluate SSI-based instruction from this point of view.

To achieve that goal, the relation between SSI and the three types of scientific knowledge that are used in the PISA test has been analysed. Accordingly, this category is divided into the following sub-categories: content, procedural and epistemic knowledge.

5.1.2.1. Content knowledge

Content knowledge is one of the key aspects of formal science education in secondary education. Also known as just “content”, it can be defined as knowledge of science, i.e. scientific facts and principles (Troy D. Sadler, 2004). Scientific facts and principles are often abstract and cannot be directly applied to daily situations. In this regard, SSI-based instruction has been seen as an example of Context-Based Learning. SSI constitute scientific knowledge in context or a situation where this knowledge is applied. The difference between this and other context-based learning approaches is that the context has some characteristics: it affects society and has a social component (political, economic, religious, ethical) that demands students’ personal implication (Troy D. Sadler, 2009a; Troy D. Sadler & Murakami, 2014).

In other words, SSI may be attractive vehicles for teachers to teach science in a more effective way. However, “science” has been interpreted very differently in educational research and practice. Studies have been developed about how to teach a specific curricular content, from vague (biology) to very concrete (the solar system, antibiotic resistance…). Indeed, content knowledge is different depending on the discipline: for example, the cycle of cell reproduction is a scientific fact and principle that students must learn about as part of the Biology curriculum. From these types of content, and pursuant to the vision of science education for a science, technology and innovation-driven society, certain content has special relevance for society at the moment. At the time when this research was developed, and
according to the PISA 2018 international assessment and other measures, the following contexts have been determined as being socially relevant: a) Health and disease, b) Natural resources, c) Environmental quality, d) Hazards, and e) Frontiers between science and technology (Organisation for Economic Co-operation and Development, 2019). The contributions of SSI to these contexts is therefore worth assessing, according to teachers, as an objective of SSI-based instruction.

5.1.2.2. Procedural knowledge

Procedural knowledge describes the standard concepts and procedures essential to scientific enquiry (Organisation for Economic Co-operation and Development, 2019). Thus, analysing how science teachers deliver SSI-based instruction to teach procedural knowledge involves looking at its affordances to convey the scientific process as a cycle of stages including: posing researchable questions, collecting data, analysing data, extracting patterns, and communicating the results of scientific research.

5.1.2.3. Epistemic knowledge

Epistemic scientific knowledge is concerned with reflection on the process of performing scientific activity itself, as a way of apprehending the natural world. This reflection takes the form of a critical analysis motivated by the following question: “what is the purpose of scientific activity?” In the current societal context, the epistemic position that is promoted is that of Responsible Research and Innovation, which establishes a new process of studying science based on the principle of responsibility. Therefore, this sub-category analyses how teachers use SSI-based instruction as a way to engage students in reflection about how scientific activity must be carried out nowadays.

5.1.3. Conveying the interdisciplinarity of knowledge

In recent years, a shift has taken place in knowledge-based societies towards breaking the boundaries between school subjects in formal education and adopting a more integrated approach, as expressed in educational reforms such as competence-based learning. In this light, science education will contribute to developing the learning goals of the discipline, as well as to learning goals in other subjects or disciplines.

SSI, to the extent that they present the application of scientific knowledge in real-life situations and are controversial, are seen as an opportunity to contribute to that goal (Zeidler
& Nichols, 2009). Therefore, SSI-based instruction has been seen as an opportunity, for example, to address other competences such as citizenship or linguistic skills in science class, as well as content from other disciplines.

5.2. Dimension 2) Components of SSI-based instruction

Another way to analyse SSI-based instruction as an educational innovation is as a set of components. On this basis, dimension 2) of this research analyses the components of SSI-based instruction. Investigating the phenomenon from this angle is motivated by the fact that there is a lack of systematic empirical evidence about how teachers facilitate student learning of SSI, and more research is needed in this area.

How to teach SSI in a science lesson has been widely discussed in the literature. Models and theory have been developed on a wide variety of teaching methodologies, assessment techniques, resources and techniques that promote student learning of SSI, and these inform the categories in this dimension. A holistic approach to teaching SSI includes the following categories:

- Teaching methods
- Techniques for discussing SSI
- Assessment of student learning

The next subsections provide an explanation of the categories that make up this dimension.

5.2.1. Teaching methods

Teaching methods are the means that are put at students’ disposition for learning (Á.-P. González Soto, Jiménez-González, & Fandos Garrido, 2012). The most common teaching method proposed to teach SSI is an adaptation of Inquiry-Based Learning (IBL), so this category is composed of only one sub-category.

5.2.1.1. Inquiry-Based Learning (IBL)

As has been reported in educational research and practice, there are several ways to organise a learning sequence around Socioscientific Issues (SSI). The specific solution that is evaluated in this investigation is grounded in a teaching method where the issue is present throughout
the lesson, in what has been referred to as a “full-fledged SSI T&L activity” (Tidemand & Nielsen, 2017).

The most common teaching method for SSI using this method is a modification of the Inquiry-Based Learning (IBL) model. In IBL, students follow similar procedures to those that professional scientists follow, such as asking questions, establishing relations between concepts, and developing knowledge based on evidence (Duran & Dökme, 2016; Pedaste et al., 2015). It is an evidence-based learning teaching method where students interact with materials that have been designed for them to achieve certain learning objectives through active engagement in learning, following constructivist learning approaches (Dobber, Zwart, Tanis, & van Oers, 2017). In that sense, it is opposed to other, behaviourist teaching methodologies where the content is transmitted to students.

According to the review of the literature performed earlier in this chapter, it is clear that when IBL is used to teach SSI, it involves students updating their knowledge about the issue in question as a result of interacting with learning materials or peers. Through these interactions, students collect evidence about the SSI and, as a result of these interactions, confirm or contradict their initial knowledge or understanding about the SSI. However, SSI are ill-defined problems that do not have a clear solution. This means that often the lessons that use SSI as a teaching and learning methodology will not necessarily lead all students to the same conclusions or results.

There are different versions of IBL, but essentially it is composed of a number of stages. These broadly include: a) formulating a researchable question and data collection strategy, b) collecting and analysing the data, and c) answering the research question on the basis of the data collected. When applied to SSI, and according to educational theory and practice, this stage model has been adapted and therefore has some differences. One of them is that there is no research question as such, but a problem that needs to be addressed, a decision that needs to be made on the basis of the evidence collected in the main activity. The second difference is that IBL is a model composed of stages, meaning that students can go back to a previous stage, for instance. The most common IBL model is that of 5E: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Bybee et al., 2006). Adaptations of this model have been used for SSI, namely the 3E model (Korkor Sam, Acheaw Owusu, & Anthony-Krueger, 2018; Marfilinda, Zaturrahmi, & Suma Indrawati, 2019).
In other words, this model is presented as a sequence where students 1) encounter the issue, which is called the “Engage” phase, 2) collect evidence as part of the “Extend” phase, and 3) propose a solution to the issue on the basis of the evidence collected, which is called the “Evaluate” phase. This is similar to the models known as Socioscientific Teaching and Learning (SSI-TL) (Troy D. Sadler et al., 2017) and Socioscientific Inquiry-Based Learning (Romero-Ariza et al., 2017). It has also been established that when IBL is used for SSI, the more complex the SSI are, the more open the inquiry needs to be (Albe et al., 2014).

Despite its similarities with certain scientific processes such as the scientific method or scientific inquiry, IBL is different from other aspects researched in dimension 1 of the present study, such as procedural scientific knowledge, because in this dimension, a teacher’s understanding about science as a discipline or activity or how it should be developed, is elicited. This dimension, in contrast, describes how to teach SSI through an enquiry process that is not scientific, but pedagogical.

5.2.2. Techniques for discussing SSI

SSI are real-life problems that do not have a clear solution. This means that discussion is a process that takes place in SSI-based instruction. Discussion involves presenting different points of view about an issue through claims and arguments. Two techniques for discussing SSI are most common, namely dilemmas and group discussion.

5.2.2.1. Dilemmas

A dilemma is a situation where a choice must be made between two options, both of them with drawbacks associated to it. Dilemmas are considered a good way to discuss SSI, based on the idea of conflict of interest, where interests or knowledge will make different people behave differently or make different decisions about SSI (Ekborg et al., 2009).

The dilemma in SSI is understood as a pedagogical strategy for engaging students in a discussion of SSI. It is one of the most discussed aspects in the literature. As a result of a review of the literature of what constitutes a socioscientific dilemma, in this research it is considered as the pedagogical formulation of an SSI adapted to the educational context of science teaching in secondary school.

The dilemma is not the same as the SSI. The dilemma has components of the discussion based, ethical aspects of science. For example, sugar drinks can become a societal issue that
brings the need to take action as a society regarding how they are advertised, to whom, and at what price, considering scientific evidence of the damage that they may cause in health. The dilemma, however, for it to be suitable for a learning activity in a formal education setting, takes that SSI and build a situation in which students must choose between two alternatives, both of them including unwanted or negative consequences. Therefore, it becomes a dilemma. Another example would be the global threat because of a new virus, and a dilemma would be "would you try a vaccine for a new virus?". The dilemma is just one possible way to discuss SSI in class.

Teacher understanding and command of the dilemma was assessed in this investigation to see to what extent teachers can promote student discussion of SSI through dilemmas.

5.2.2.2. Group discussion

Group discussion is an organised discussion activity that takes place among a small group of students. Discussion in science class has been recognised to have unique features that make it different from discussion in other subjects (Shwartz et al., 2009). The important role teachers play in group discussion of SSI with respect to justification of student claims has been empirically demonstrated (Bossér & Lindahl, 2020). Group discussion is a common technique in SSI-based instruction and it is different from using group discussion to discuss other topics, because in a group discussion about SSI students are expected to express not only their personal view about the SSI but about the scientific claims behind it (Åkerblom & Lindahl, 2017; Lewis & Leach, 2006). However, this is not common for science teachers. Therefore, their interpretation of group discussion as a way to engage with SSI has been analysed in this study.

5.2.3. Assessment of student learning

As was noted in previous sections, there are different components of SSI-based instruction. Assessment is defined in broad terms as actions that consist of gathering data oriented to understanding student progress in relation to the experience of learning an SSI, in order to modulate or improve it (Bordas, 2005). Assessment is a very important aspect in formal secondary education and, within this educational context, is unique and different from others such as non-formal or informal. Assessment is usually divided into student learning outcomes and process. In SSI-based instruction, assessment of student learning outcomes is of concern, because it may have specific characteristics compared to assessment of other
types of instruction. Data about how teachers assess the following aspects has been collected in this research: a) what is assessed, b) assessment strategies.

5.3. Dimension 3) Resistance to SSI-based instruction

This dimension analyses resistance to SSI-based instruction in the educational context of secondary school from the point of view of science teachers. It is known that teachers face challenges to incorporate SSI into their practice (Ariza et al., 2014; Garrido Espeja & Couso Lagarón, 2015; Romero-Ariza et al., 2017). However, as stated by Garrido and Couso: “there is very little research regarding teacher education or about the difficulties of teaching SSI in the classroom” (Garrido Espeja & Couso Lagarón, 2015), p. 81. However, this is a dimension that, in the same way as the other two dimensions, has garnered interest in recent years.

This dimension is grounded in the assumption that any intentional change of existing practices requires effort, learning, and adaptation, to the extent that it takes the space of existing practices (Jiménez-González et al., 2012). In this case, teacher perceptions of this resistance are of special interest because their perceptions are known to be even more important than the objective nature of the resistance. This has been expressed in research about SSI and teachers, although with a different objective: “conceptions about the curriculum (and not the curriculum itself) emerge as an important inhibitor of the attention that teachers pay to the discussion of SSI” (Albe et al., 2014), p. 62.

After reviewing the literature, the most common sources of resistance to SSI-based instruction in science education, from the point of view of teachers, have been selected to be addressed in this study:

- Resistance on students
- Resistance on content load
- Resistance on organisation, schedule, and timetable

Each category is explained in detail in the following subsections.

5.3.1. Resistance on students

SSI-based instruction invites students to take on a role in learning that is new and different from science instruction based on stable, factual scientific knowledge. Because SSI are ill-defined problems to the extent that the scientific claims sustaining them are under discussion,
students are required to be engaged in the learning experience by expressing their opinions, arguments, and reasoning, and considering the points of view of peers. In fact, it is known that teachers find it very difficult to promote and manage this role among students in a science class (Bossér et al., 2021; Lee & Yang, 2019). Therefore, this is considered one source of resistance to SSI-based instruction. In particular, resistance from students has been expressed in this investigation as per the following sub-categories: 1) Participation and 2) Personal engagement.

5.3.1.1. Student participation

This sub-category describes students expressing their opinions and communicating about different aspects of SSI. This aspect is key for SSI-based instruction, seeing that students learn about the SSI by confronting their initial beliefs or positions with those of peers, the teacher, or stakeholders involved in the SSI. However, student participation in learning is seen in this investigation as an obstacle to SSI-based instruction, to the extent that science teachers may not be used to promoting it, as opposed to teachers from other disciplines or educational levels. Therefore, the lower the participation is, the less rich this process will be. To shine a light on this question, this study analyses the factors influencing student participation and the techniques teachers use to achieve this goal.

5.3.1.2. Personal involvement in the SSI

In the same way that student participation is key in SSI-based instruction, the kind of participation elicited is important as well. As per theoretical models, SSI learning is best when students are personally engaged in the SSI. This means that they become involved in it as if it were a personal issue, take ownership of it and approach it as something they are in charge of solving, or contributing to solving. However, it is hard for science teachers to achieve students' personal involvement in the SSI, because it contradicts the way students are expected to behave in learning science, not SSI. In this research, the difficulties that students and teachers face are studied, as well as how these challenges affect the process of teaching the SSI.

5.3.2. Resistance on the content load

Delivering SSI-based instruction in secondary school means that new topics, which may or may not be part of the curriculum, are taught in science class. However, the science
curriculum at this educational level is recognised as very full given the amount of time that teachers must cover it. This pressure is due to factors that are external to teachers' range of action but that they affect their professional activity, such as university entry exams and external evaluation. Indeed, one source of resistance to teachers delivering SSI-based instruction is the heavy content load of national science curricula (Christodoulou, Amos, Grace, & Levinson, 2017; Lee & Yang, 2019; Steffen & Hößle, 2014). In other words, in order to teach SSI, other activities or content need to be moved or integrated. This category has been called “Content load” in this research, and it investigates in which ways teachers make teaching SSI compatible with this need.

5.3.3. Resistance on the organisation, schedule, and timetable

Another characteristic of teaching science in secondary school is the structure of instruction, which is organised in a weekly schedule, usually divided by subjects. This means that teachers must work within the structure of a lesson. Lessons may range from fifty minutes to two hours with the same group of students, with a frequency ranging from two to three times per week. This fixed structure is known to represent an obstacle to SSI-based instruction as an innovation in science education, because it is common that both teachers and students need more time to learn about an SSI than about other content. Therefore, SSI require more flexible organisation, in terms of schedule, interdependency with other subjects (and teachers), etc. This sub-category analyses how these challenges appear in the specific case of the SSI that were offered to teachers in this research, and how teachers address them.

5.3.4. Resistance on teachers’ choice of SSI

This category investigates teachers’ choice of SSI as a source of resistance to SSI-based instruction. There is evidence in the literature that teachers encounter difficulties in one aspect in particular, which is how to choose the right SSI for their group of students. How teachers resolve this challenge has been investigated as part of this dimension.

5.4. Summary of dimensions of analysis of SSI-based instruction

The following list summarises the research dimensions of the present study, as well as their sub-categories and categories.

- Dimension 1: Objectives of SSI-based instruction
- Contribute to developing scientific literacy
  - Explaining phenomena scientifically
  - Evaluating and designing scientific enquiry
  - Interpreting data and evidence scientifically
- Teach scientific knowledge
  - Content knowledge
  - Procedural knowledge
  - Epistemic knowledge
- Conveying the interdisciplinarity of knowledge

- Dimension 2: Components of SSI-based instruction
  - Teaching methods
    - Inquiry-Based Learning
  - Techniques to discuss SSI
    - Dilemmas
    - Group discussion
  - Assessment of student learning

- Dimension 3: Resistance to SSI-based instruction
  - Resistance on students
    - Student participation
    - Personal implication in the SSI
  - Resistance on content load
  - Resistance on organisation, schedule, and timetable
  - Resistance on teachers’ choice of SSI
CHAPTER 3

METHOD AND RESEARCH DEVELOPMENT
Chapter 3: Method and research development

This chapter defines the methodological aspects of the study. These aspects can be described as the research design or planning, and its implementation.

The chapter is divided in three sections. The first section presents the research questions that guided the investigation, namely a main research question, and three sub-questions.

The second section, called "Methodological approach", presents the decisions made at the different levels that constitute the methodology of the present study, from the most abstract to the most precise. It presents the reasoned choice of the research paradigm, as well as the specific understanding of the case study research design that was chosen. As part of that section, information is provided in detail about how the participants were selected, as well as a description of the data collection sources and instruments. Then, detailed information is provided about the two case studies that are analysed. The last two subsections deal with the quality of the research and its ethical aspects, respectively.

The third and last section of the present chapter reports on how the research design, instruments and procedures were applied in practice. Therefore, it accounts for the steps followed in collecting and analysing the data.
1. Research questions

The present research is concerned with the educational phenomenon known as SSI-based instruction. Within this context, a specific problem was identified and was formulated in Chapter 1: Introduction and research problem. In order to address this problem, research questions were determined.

Formulating research questions is a key tool in guiding any research, because it helps to narrow the scope of the problem, determine the purpose of the research, as well as inform the procedures and means to develop it (Creswell, 2012; Sabariego Puig & Bisquerra Alzina, 2009a). The present study aims to answer the following main research question (RQ):

**RQ: How do secondary school science teachers deliver SSI-based instruction as a way to innovate in their practice?**

In order to answer the main research question, this study is driven by 3 sub-questions (SQs):

1. **SQ1:** To what extent do teachers think that SSI-based instruction is a way to help students develop conscious and active citizenship in science education?
2. **SQ2:** How do science teachers develop SSI-based instruction as part of a lesson?
3. **SQ3:** Which opportunities are there for SSI-based instruction, and which challenges does it face in secondary school science teachers' professional practice?
2. Methodological approach

Educational research aims to develop reliable and systematic knowledge about educational realities, which allows to understand it and intervene on them. Because of its potential to transform reality, as part of educational research it is necessary to practice self-awareness about the purposes, the goals and the procedures of the activity of research itself. Worthwhile, rigorous studies make explicit all these choices, in an attempt to create a shared understanding about their influence in the research with its possible readers (Creswell, 2007). To that goal, the following sections account for the methodological aspects of the study that is described and reported in this dissertation.

The following subsections describe the research paradigm, the research design, the data collection sources, the selection of participants, the quality of the research, the ethical issues and the role of the researcher in this investigation.

2.1. Research paradigm

The research goals that are established for this investigation enable to reach the conclusions concerning the object of study, namely SSI-based instruction. However, in order to approach the object of study, educational research establishes a set of processes that bridge the gap between the reality being studied and these conclusions. One of these strategies is to define the research paradigm.

Since it was introduced by Kuhn, the research paradigm is a well-established framework in social sciences research, that based on making explicit the way the reality being studied is conceived and interpreted (Guba & Lincoln, 1994; Sandín Esteban, 2003). The paradigm can be seen as a set of ontological, epistemic and methodological assumptions that help to establish the more practical aspects of the investigation.

2.1.1. The three research paradigms

The complexity of education as a subject of research has long been acknowledged and it has led to multiple perspectives or paradigms to approach it (Sabariego Puig & Bisquerra Alzina, 2009b). There is a lack of agreement about a single set of paradigms and there are difficulties to make statements about the boundaries of each. However, the three main paradigms in
educational research have been reviewed for the present study: positivist, practical-interpretive, and critical.

The positivist approach starts from the ontological assumption that educational reality is given, objective and measurable (Sandín Esteban, 2003). On this basis, the goal of research is to explain such reality as a system formed by causal relationships, where phenomena can be explained as result of another. For this reason, it is common that research following this methodology starts from theories and uses the reality as an empirical proof of those theories. To that goal, hypotheses and variables are used, and participants in the research are chosen according to a set of criteria that will make the results obtained generalizable to other, similar realities (Guba & Lincoln, 1994).

The practical-interpretive paradigm conceives reality as subjective and co-constructed among its participants. Hence, research approaches reality with the epistemological aim to understand or interpret it, as it is perceivable from the actions taking place. Thus, the knowledge created following the practical-interpretive paradigm is valid in a given context. The main characteristic of the practical-interpretive paradigm is that researchers approach reality in its naturally occurring context, with a minimal degree of interventions. That is one reason why some authors refer to it as "naturalistic" (Sandín Esteban, 2003). This means that research is performed in the natural situation, as it is, without the control applied in experimental methodologies. Some of the research methods associated with this paradigm are: Ethnographies, narrative research, case studies, grounded theory.

The critical paradigm sees reality as co-constructed and shared between the participants and the researchers. On this basis, educational research following the critical paradigm share the principles of the practical-interpretive paradigm, but aim to overcome its limitations by using research to transform society. It aims for liberation and identification of potential to change such reality, by creating knowledge that is accepted and valid only within the boundaries of such reality (Sandín Esteban, 2003). Therefore, its research methodology is usually participative, where the members of the reality analysed become empowered with the knowledge gained through methodologies such as action research, and by using data collection strategies such as dialectic techniques.
2.1.2. Research paradigm chosen for this research: practical-interpretive

The present study follows the practical-interpretive paradigm. A key characteristic of this paradigm is that knowledge comes as a result of an in-depth understanding of a reality that is co-constructed, hence such knowledge becoming an interpretation of reality. The practical-interpretive paradigm is consistent with the socio-educational perspective to research. This perspective is based on the conception of education as a context-bound, culturally-defined phenomenon, where the explanations or predictions about a reality do not aim to apply to other ones. As some authors express: “Learning about teaching is situated. The context in which an activity takes place is as important as the activity itself (Lave and Wegner, 1991; in Wallace, 2003b, p. 10. In this sense, positivist paradigm was considered not useful because the specific understanding of SSI that is made in this investigation is where they are different in different countries and cultures. This research does not fall either in the critical paradigm. Although this research is developed in the framework of an educational innovation that in a way constitutes a change or raise of awareness within its participants, the objectives of the research that has been developed within it did not have as an objective the empowerment or using research as a means to be able to improve participants’ own reality.

The choice of a paradigm ensures the consistency between what are known as the methodological levels of any research (Guba & Lincoln, 1994; Sandín Esteban, 2003). How such consistency has been ensured in this study is explained in Table 2 below.

<table>
<thead>
<tr>
<th>Ontology</th>
<th>Epistemology</th>
<th>Methodology</th>
<th>Data collection strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence of multiple realities according to teachers</td>
<td>The researcher understands reality by participating and sharing the same constructs of meaning as the participants</td>
<td>Looks for meaning and subjective interpretations Deductive analysis starting from categories established in the literature, but flexible to add new emerging categories Awareness of the influence of the researcher views in the interpretation of the results</td>
<td>Open and non-invasive, based on text (&quot;teachers' words&quot;) and actions.</td>
</tr>
</tbody>
</table>

Table 2: Consistency between the methodological levels of this research
2.2. Research design

In this study, the research design is defined as a set of decisions that are made regarding how the data is collected, analysed and interpreted (Creswell, 2012). This section presents the reasoned choice of multiple case study design and describes the cases that constitute this investigation.

2.2.1. Research design chosen for this study: Multiple case study

The chosen research design for this investigation is multiple case study. The focus of the case study is on "developing an in-depth understanding of a case, such as an event, activity, or process" (Creswell, 2012, p. 477). According to the author, case study has components of ethnographic design, as it is concerned with groups of people. In this specific investigation, the subjects are secondary school science teachers.

This investigation deploys case study as a strategy of inquiry for several reasons. First, case studies are useful "when the study of a group provides understanding of a larger issue" (Creswell, 2012, p. 462). In other words, the culture-sharing group has a pattern of beliefs and behaviours and it is representative or illustrative of a larger activity. In this research, the activity that is represented by this case is science teaching from the perspective of SSI-based instruction. Second, case studies are best suited to address a "how"- type of question about a contemporary set of events, over which the researcher has little or no control" (Yin, 2014, p. 14). In this study, how teachers apply SSI-based instruction as an innovation in their workplace is studied, which is a phenomenon taking place in a real setting where the researcher does not intervene. Finally, case studies have already been used to research on teaching Socio-Scientific Issues (SSI). For example Klosterman, Sadler, & Brown, (2012).

As part of the process of this research, a critical analysis of different research designs was made in order to determine the most suitable research design to answer the research question. From all the common research designs (Creswell, 2012), grounded theory was considered in most detail (Glaser & Strauss, 1967). Grounded theory design is appropriate when the goal is to develop theory as emerging from the data, to explore a phenomenon that is new, where there is a lack of concepts to explain what is happening (Dorio Alcaraz, Sabariego Puig, & Massot Lafon, 2009). This is precisely the case of SSI-based instruction, which is relatively new teaching practice. However, case study was considered more useful given the need to complete this investigation within the time and resources available.
More specifically, this research deploys multiple case study, where two cases are described and compared. Following Yin, (2014), the cases serve to produce similar results (literal replication), as opposed to contrasting ones (theoretical replication). One of the reasons for choosing two case studies is because it will provide more information and validity to the findings. Sequential analysis has been used, where the data collected in case 1 was first analysed, and trends and themes identified within the three research dimensions determined. Then, this information was completed, refined and deepened with the data collected in case 2. This process is shown in figure 14 below. Finally, and following Stake (1999), these constitute instrumental case studies because they aim to illustrate an issue. In other words, i.e. SSI-based instruction is studied in the case of the two educational interventions that constitute the cases in this research. The cases are described in detail further on in this section.

![Figure 14: Process followed to determine the case study research design](image-url)
2.3. Selection of participants

One of the common procedures to select participants for a case study is convenient sampling. This way to select participants is known for not selecting them randomly, but the main criteria is that they are available and motivated to participate. This is the criteria that was used in the present research. All teachers participated in it voluntarily, they had no direct compensation, they are intrinsically or extrinsically motivated but at least they are engaged in this innovation (Creswell, 2007). This way to select participants naturally ensures that they work in different schools. This is important in an innovation that aims to be used in diverse educational contexts such as SSI-based instruction. The teachers who participated in this research, because they were not chosen but enrolled themselves, are thought to represent the diverse reality that can be found in formal education.

The general characteristics of the participants in this research are the following: a) they are located in Spain, b) they work in secondary school, and c) they teach science subjects (any generic course known as natural sciences, or specific courses such as biology-geology, physics-chemistry). Additionally, they are considered innovative, as they want to innovate in their teaching practice by including SSI-based instruction.

Nevertheless, it is not necessarily sufficient that a teacher is motivated towards the educational innovation in order to be a useful informant for the investigation. Therefore, from the more than a thousand teachers who showed interest in the SSI materials, the a few criteria were determined and applied to select participants for this research.

First, the cultural context was determined. Data provided by teachers from Latin America was discarded. Despite sharing Spanish language and some cultural aspects, the formal education systems of Latin American countries and Spain cannot be considered as the same case because of their differences in the curriculum, school organisation and teachers' professional practice.

Second, the educational context and level was considered. The participants selected work in secondary school (students usually aged between 11 and 18). The Engage materials (see Chapter 1: Introduction and research problem) raised interest from teachers working in a diversity of educational settings, including formal and non-formal. Non-formal education contexts include companies offering extracurricular activities such as tutoring or science-thematic workshops addressed to students or even their families. Participants working in
these settings were discarded because they constitute an inherently different educational context, due to its higher degree of freedom in terms of content and pedagogies to use than formal education, as well as organisational differences regarding number of students per class or requirements for hiring teachers. Within formal education, participants worked in different educational levels, such as primary, secondary and higher education. It was decided to keep only the teachers from secondary school because this the level that the Engage materials are designed for. For the same reason, data from teachers who reported being affiliated with adult training and vocational training were considered as part of the case because the curriculum and organisation are similar to those from secondary education.

Third, the discipline they teach was taken into account. Participants teach "science" subjects, i.e. biology, geology, physics, chemistry, or any general science course known as natural sciences. Despite the trend to integrate Science, Technology, Engineering and Mathematics what is known as STEM subjects, SSI-based instruction is mostly delivered in science subjects. Accordingly, data provided by teachers who stated to be teaching only in mathematics, technology, or other subjects other than science, was only considered if the teacher met all the other criteria. Teachers who did not provide information about the discipline they teach were discarded as well.

Additionally, the criterion of availability for providing data for the study was applied. The teachers who participated in the project to a sufficient extent were selected, by meeting the following criteria: a) teachers responded to more than one data collection instrument, and b) they participated consistently in the activities proposed in each case. More information about the participants is available in Appendix 2.

2.4 Data collection strategies

The present study makes use of a multiplicity of data to understand the reality of teachers' delivery of SSI-based instruction, thus extracting information to respond to the research questions in a reliable way. Three types of data can be collected in educational research, namely quantitative, qualitative, and mixed. Quantitative research is interested in generalizability, in gathering superficial knowledge about a high number of participants (Creswell, 2012). Instead, qualitative research looks for meaning and subjective interpretations (Erickson, 2012). As stated by Yin (2003): "Case studies can be based on any mix of quantitative and qualitative evidence" (p. 15). On the basis of a review of the three approaches identified above, this study works with qualitative data.
In order to collect the data, strategies were used, which are consistent with the groundings and the goals of the investigation and aim to providing a wide angle view to the reality. For this reason, all the data comes from teachers. As opposed to directly observing their practice, teachers freely decided to share with the researcher the data requested. This approach is considered to be non-invasive in their teaching practice and allows teachers to continue developing their practices as usual while the research ongoing. Moreover, it is adapted to the high number of participants in this research, spread in different schools and different regions.

2.4.1. Main data collection strategies

The main data collection strategies were designed to accurately access the data of the reality of teachers' delivery of SSI-based instruction, which is the object of study in this investigation. The main data collection strategies used are open ended questionnaire and reflective diary.

2.4.1.1 Open ended questionnaire

To access the data about teachers' delivery of SSI-based instruction as an educational innovation, this study made use of the open ended questionnaire. This technique was adapted to the specificities of the two cases that constitute this multiple case study research. In case 1, where teachers are part of an educational intervention that is a Professional Development (PD) course, the questionnaire focussed on eliciting teachers' knowledge and practices about SSI-based instruction. The questionnaire was developed on the basis of the review of the literature about teachers' pedagogical knowledge (PK) (see Chapter 2: Theoretical framework). The questions were adapted from the original proposal by the PD designers, which aimed to promote teacher learning about SSI-based instruction. The PD designers were experts in science education research and educational materials developers. The instrument was reviewed by one expert in the field, Mr. Dr. Jordi Domènech, who is an associate lecturer at Autonomous University of Barcelona, member of a research group about Didactics of Science, and secondary school science teacher. As an expert and recognised practitioner in the field of science education, he provided his opinion, which was considered in the final version of the questionnaire. The questionnaire was administered as

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3 https://jordidomenechportfolio.wordpress.com/
part of the activities that the teachers had to do in order to plan, adapt or implement one or more SSI materials.

In case 2, the open ended questionnaire collected data about the specific reality of using SSI-based instruction as a one-off activity in the framework of a lesson by using the framework of Pedagogical Content Knowledge (PCK), as introduced in Chapter 2: Theoretical framework. This is a useful framework considering that teachers are putting in practice a specific Engage material, which aims to teaching specific content. The questionnaire was designed on the basis of a validated model by Mrs. Dr. Durdane Bayram-Jacobs, assistant professor at the Eindhoven School of Education, Eindhoven University of Technology (The Netherlands). The questionnaire was reviewed by a group of international researchers in Science Education, including Mrs. Dr. Maria Evagorou from Nicosia University (Cyprus). Both the questionnaire for case 1 and the questionnaire for case 2 were piloted with a small group of teachers and refined. They are available in Appendix 3.1.1 and Appendix 3.1.2, respectively.

The questionnaires were administered differently depending on the case. In case 1, demographic data was obtained when teachers signed up for the PD, and the rest of items were distributed through forum posts and weekly assignments. The difference between forum posts and assignments is that assignments were compulsory and counting for obtaining a course certificate, whereas participation in the forums was optional. In case 2, the questionnaire was administered before teachers delivered a lesson in which they used an Engage material.

2.4.1.2 Reflective diary

In addition of being a way to promote teacher learning, reflections about their own practice is a very common way to elicit teacher knowledge and beliefs (Loughran, 2002; Scales, 2012). Reflective journals have been used in previous investigations eliciting teachers' delivery of SSI-based instruction (see Saunders and Rennie (2013), as well as to research educational innovation.

While all the data collection strategies were designed to collect the necessary information to answer the research questions, the reflective diary allows to collect very valuable information, because teachers analyse their own experience with SSI-based instruction. This strategy, thus, contributes to collecting information for the three dimensions of analysis of SSI-based
instruction, but in particular those dimensions that evaluate it in a critical way, for example about the challenges faced in practice. Consequently, the analysis of this data was performed following the framework of opportunities and resistances to educational innovation, based in the theories reviewed in Chapter 2: Theoretical framework.

2.4.2 Triangulation data collection strategies

Triangulation is one of the main features of validity in qualitative research, as it increases its quality by reducing the risk of the results of the research being due to the application of one single data collection method (Cohen, Manion, & Morrison, 2007). In particular, the present study uses triangulation of data sources because different data collection instruments are deployed to answer the same questions (Patton, 2015). Thus, it allows to certify that the data obtained through the main data collection sources is reliable.

As a way of data triangulation, information about what teachers do, i.e. how they deliver SSI-based instruction with the Engage materials in the actual classroom was collected. Teachers' outline of the lesson and videos were used.

2.4.2.1 Teachers' outline of the lesson

As triangulation data collection strategy for case 1, teachers provided outlines of the lessons they delivered where they used an Engage material. A lesson is usually 50-60 minutes long, and it has an introduction, a development and a closing, as well as indicators of assessment. Teachers make lesson plans as part of their professional practice, which they use as guides to the activities that will take place in the classroom. As a data collection strategy, teachers' outline of the lesson reflects how teachers convert or adapt an Engage material into a lesson. This strategy was chosen as it is thought to reflect how teachers adapt the materials to the secondary school science class context. Moreover, samples of products generated by teachers in educational interventions using SSI-based instruction have been used to elicit how they deliver it in practice, for example Saunders and Rennie (2013) and Friedrichsen et al. (2020).

In both case, teachers were asked to provide the outline of the lesson after they applied an Engage material in class. For each case, however, the questionnaire was adapted to the specificities of the intervention, as it can be observed in Appendix 3.2.1 and 3.2.2, respectively. Teachers provided the outline of the lesson in a variety of formats, mostly text, but also presentations or conceptual maps. The data was analysed following the three-
dimension framework of analysis of SSI-based instruction that was developed for this investigation and that is available in Chapter 2: Theoretical framework.

2.4.2.2 Lesson observation

As triangulation data collection strategy for case 2, teachers provided video recordings of a lesson where they used one Engage material. They recorded the video themselves, by leaving the camera in a corner of the classroom, or they asked a colleague to record the lesson. The teachers were instructed to leave the camera still, pointing to the teacher. Therefore, the teacher faces the camera and students give their back. The teachers sent the videos digitally through an online file sharing system, in one file or split in a few files. The videos were watched and coded following an observation grid. The grid is based on the three dimension framework of analysis of SSI-based instruction that was developed for this investigation. The grid is provided in Appendix 3.4.

2.4.3 Summary of the data collection strategies

The data collection strategies that were described in previous subsections were developed through data collection sources, and the information collected in these sources was analysed with suitable frameworks. What follows is a table that synthesizes the data collection strategies used in this study.
<table>
<thead>
<tr>
<th>Strategy</th>
<th>Source</th>
<th>Analysis tool</th>
<th>Cases</th>
</tr>
</thead>
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<td>Discussion forums</td>
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</tr>
<tr>
<td></td>
<td>Online form</td>
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<td>2</td>
</tr>
<tr>
<td>Reflective diary</td>
<td>Assignments</td>
<td>Criteria of opportunities and resistances to educational innovation</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Online form</td>
<td>Criteria of opportunities and resistances to educational innovation</td>
<td>2</td>
</tr>
<tr>
<td>Triangulation: teachers' outline of lessons with the Engage materials</td>
<td>Assignments</td>
<td>3-dimension framework of analysis of SSI-based instruction</td>
<td>1</td>
</tr>
<tr>
<td>Triangulation: lesson observation</td>
<td>Videos</td>
<td>Lesson observation grid, based on the 3-dimension framework of analysis of SSI-based instruction</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3: Summary of the data collection strategies, instruments and frameworks of analysis used

### 2.5. Description of the cases

As part of an interpretivist study, it is essential to describe the reality being analysed in detail, so that other researchers can decide to which extent the findings can be generalised (Cohen et al., 2007). As stated above, the present study is composed by two cases, which are described in detail below.

#### 2.5.1. Case 1

This case is composed by a group of teachers who participated in a Professional Development (PD) developed as part of the Engage project (see Chapter 1: Introduction
and research objectives). The objectives of the PD were to guide teachers in planning or implementing science lessons using the Engage SSI materials. To that goal, contents and learning activities were designed.

Forty-five (45) teachers compose this case. The participants have the following characteristics: thirty-two (32) teachers, which is more than half of the total of participants in this case, are between 30 and 49 years old, and ten teachers are older than 50 years old. Thirty-six (36) are female, and nine are male, as shown in figure 15 below. Thirty-two (32) participants teach only in compulsory secondary level, and five teach only in post-compulsory secondary level. Five participants teach in different levels across compulsory and post-compulsory secondary level. Two teachers work in adult education, and one teacher works in vocational training.

![Participants in Case 1](image)

**Figure 15: Distribution of the age (left) and gender (right) of participants in case 1**

Twenty-six (26) teachers have more than 10 years of experience in teaching, and nine teachers have between 6 and 10 years of experience. Only ten teachers have between one and five years of experience, although from those, eight have only one or two years of experience.

The teachers in this case belong to forty-five (45) different schools, which means that there is not more than one teacher from the same school. Most of the schools are located Spain, and one school is located in Rabat (Morocco), but it is a Spanish school that follows the Spanish education system and curriculum. Schools are distributed across the Spanish state. 34 of the schools are located in Catalonia, which is an autonomous community located in the North-East of the country (see figure 16). The rest of schools are located in other autonomous communities, namely Andalusia, Asturias, Madrid, Valencia, Galicia, Castille and Leon, Castille La Mancha, and the Basque Country. Schools from diverse cultural
contexts are represented, in terms of rural and urban area, big cities and secondary cities, as well as public and private schools.

The PD lasted for twenty (20) hours distributed in six weeks. It was designed by a team of independent professionals, including developers of curriculum materials, as well as science education researchers. The PD had the following characteristics:

- Teachers were active, to learn and construct their own knowledge. This way they develop ownership toward the products of their learning, responding to the principles of constructivism. Teachers used evidence from their classes for what worked and what did not, and discussed possible reasons and changes. This approach is a softer version of "teachers investigating their own teaching". This will also increase the link of what they learn in the PD to their practical work in class.

- Teachers were treated as professionals. The teachers’ existing knowledge and teaching experience were highly regarded, and played a key role in all activities. Teachers self-experience as learners should be in line with what is expected they do with their students, since this self-experience has a role in shaping teachers beliefs (Pajares, 1992).

- The PD provided opportunities for the development of different types of teachers’ knowledge. These are Content knowledge; Pedagogical knowledge; Pedagogical-Content Knowledge (PCK), and Technological Pedagogical-Content Knowledge (TPACK), which defines the interface between teaching approaches and content (Kind, 2009; Koehler & Mishra, 2009; Shulman, 1986).
The PD included content regarding pedagogical components of SSI-based instruction, such as Inquiry based learning (IBL), and techniques to discuss SSI, namely the dilemma and group discussions. The training modules were distributed in a virtual form, using the Open edX platform. Open edX is an open-source Learning Management System that allows to create weekly sections with the content of each week, as well as other modules such as forums or assignment delivery.

The content was distributed in a multi-media format, through presentations, readings, and videos. The PD included learning activities such as planning the implementation of one Engage material, or answer questions about a reading or a video.

![Figure 17: Screenshot of the online PD course, in Spanish (week 3)](image)

The PD took place two times, with similar contents and activities, and teachers from the two iterations of the course have been included in case 1.

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4 https://open.edx.org/
2.5.2. Case 2

This case is composed by a group of seven teachers who participated in an international, quasi-experimental study about how in-service science teachers develop knowledge as they plan, implement and reflect over a lesson using an Engage material. This is considered an educational intervention as well as the PD course that the teachers in case 1 participated in, to the extent that these teachers are interested in SSI-based instruction and they want to try it out. The educational intervention included a total of thirty (30) teachers from four countries (Cyprus, Israel, Norway and Spain).

Five out of the seven teachers are between 40 and 49 years old. One teacher is between 30 and 39 years old, and another teacher is older than 50 years old. Three teachers are female, whereas four are male.

![Participants in Case 2](image)

Three teachers have between three and six years of teaching experience, and the other four teachers have more than 10. Each teacher belongs to a different school. Three of them are located in the autonomous community of Catalonia, two of them in the autonomous community of Valencia, and one teacher in Madrid. Six participants teach Physics and Chemistry in compulsory secondary level, and one participant teaches Biology and Geology.

The teachers implemented a lesson with an Engage material and provided data through the data collection instruments mentioned above. They used the presentation, teacher guide, and student sheets of the material without any previous training. They participated on a voluntary basis, but their participation was recognised with a certificate from the University of Barcelona.
2.6. Quality of the research

In addition to choosing a paradigm that informs the approach to the reality and the data collection strategies, there are a series of principles to ensure the quality of any educational research. These principles are different according to the nature of the research, for example in terms of quantitative and qualitative data: whereas criteria such as reliability or replicability are used in the former, terminology such as trustworthiness is used for the latter (Cohen et al., 2007; Lincoln & Guba, 1985).

Yin (2003) establishes a set of criteria for judging the quality of empirical social research, and case studies in particular: 1) Construct validity, 2) Internal validity, 3) External validity, 4) Reliability. The following subsections account for how each criterion has been addressed in this research.

2.6.1. Construct validity

This criterion is based on the principle of co-construction of knowledge, i.e. the awareness that the theoretical constructs that are used to apprehend reality are only valid to the extent that they are shared in the research community. To that goal, it measures to what extent the case study includes objective definitions of the constructs, instead of leaving them to the free interpretation of the researcher. In the present study, this criterion has been addressed by clearly defining the constructs in this research in terms of specific concepts. The concepts are defined in Chapter 2: Theoretical Framework. Besides, the study is based on previous studies that work on the same interpretation of these constructs.
In practical terms, construct validity has been ensured in this study through participant selection. Some constructs, which are relevant to SSI-based instruction, were used in the data collection strategies, including: the curriculum, a lesson, content knowledge, student skills and attitudes, and the 3E model to inquiry-based learning. In this research a shared understanding of these constructs is ensured by choosing participants who work in formal education, in secondary school in particular, and teach science subjects. This means that these teachers have received similar initial training and developing similar tasks in their workplace. They belong to science departments where these constructs are used frequently as part of their professional practice. In the case of the construct "curriculum", for instance, the data collected shows a high level of shared understanding about this concept, seeing that teachers refer to curriculum specifications, evaluation criteria, and specific educational legislation. Furthermore, especially in case 1, some information about these constructs was provided as learning resources in the PD course. This fact increases the probability to achieve a sufficient shared understanding of the constructs.

2.6.2. Internal validity

A common concern in qualitative research is the need for objectivity in the process of abstraction from verbatim data to conclusions. Internal validity has to do with the causal relationships established between the evidence and the conclusions. In the specific case of case studies, this concern is expressed as the problem of making inferences from the data, where "the findings must describe accurately the phenomena being researched" (Cohen et al., 2007, p. 135). In order to meet this quality criterion, the data analysis process has been made explicit to the reader, and it can be consulted further on in this chapter.

As part of the actions taken to ensure the internal validity of the present research, it is worth making explicit the language aspect. The data collection sources were administered in Spanish language. This means that the data collected is in Spanish or other co-official languages such as Catalan. In contrast, this study aims to being of as much value as possible for educational research, whose language of exchange is English. For this reason, although the raw data has been kept in the original language, the knowledge derived from that data is articulated in English in the present document. This is not considered to be a problem in terms of internal validity, because it is a common procedure in educational research.
2.6.3. External validity

External validity refers to the generalizability of the study (Yin, 2014). As other authors have expressed it, it describes "the degree to which the results can be generalised to the wider population, cases or situations" (Cohen et al., 2007, p. 136). In the specific case of this investigation, qualitative inquiry does not aim to generalize for other contexts, but for similar cases, for example in a similar cultural context in terms of science curriculum. This is called analytic generalization, as opposed to statistical generalizations, which are more common in experimental research designs (Yin, 2014).

2.6.4. Reliability

Reliability refers to the possibility of another researcher to analyse the same case and arrive to the same conclusions. To that goal, different techniques were used in this research, including making explicit the process of abstraction from the raw data to higher level constructs or assertions, and documenting the procedures through memos. This research also assumes that teachers' responses to the questions posed truthfully reflect their beliefs, behaviours, and realities. They are free to answer because they are in a comfortable environment full of other peers (teachers) or researchers or project facilitators, with whom a relation of authority has not been established.

As part of the effort to increase the reliability of the study, results were shared with participants in an information exchange session at University of Barcelona, Faculty of Education, which took place in January, 2017. In this wrap up session, participants shared their experience with the Engage materials, and the researcher provided information about the progress of the research (see figure 20 below).
Additionally, the preliminary findings were shared with colleagues at University of Barcelona (Faculty of Education), but also with colleagues from other universities. Mainly, they were presented in the weekly seminars of the PhD programme in Didactics of Science at University of Lisboa (Institute of Education). Feedback was obtained from senior professors as well as PhD candidates, which was considered in the study.

2.7. Ethical aspects

Any research must comply a set of ethical aspects. This aspect used to be mainly relevant the domain of experimental sciences, but nowadays it is being applied in social sciences as well. Educational research, as part of social sciences research, must cater for ethical issues. On this basis, the University of Barcelona’s code of conduct for research integrity has been taken as a reference for the present study (Vicerectorat de Recerca de la Universitat de Barcelona, 2020).

2.7.1 Ethical principles

A few principles informed this research. In case study research in particular, especial attention was put into the fact that the researcher has an open mind, being as objective as possible, as opposed to using the case study to confirm a preconceived position (Yin, 2014). All the other principles of research ethics, and case study research ethics in particular, have been considered in this study, such as honesty throughout the whole research process and respect towards the participants in the research.

Particular attention was given to how the data and the results of this research were collected and processed. The data in digital form was carefully stored and organised in the researchers’ file system, and they are easily findable, accessible and reusable.

Regarding the fact that this research involves human beings, participants were made aware that their personal data (name, age, gender, years of experience, area of knowledge, school) was being collected for research purposes in different ways. For example, in order to access the Engage materials, they had to register on a the Spanish version of the site http://www.engagingscience.eu, namely http://www.engagingscience.eu/es. The registration form included the following compulsory fields: username, email, school / institution, job category, and country.
Additionally, in this form teachers could provide information about their first and last name, website, city, and postcode, as shown in figure 21 below. The information about how their data was being processed was provided in several of the communications that were made with teachers, such as those available in Appendix 4.1., 4.2., and 4.3.

Figure 21: Registration form to log into the site http://www.engagingscience.eu

In Case 1, participants were informed that the Professional Development (PD) course was part of an educational project funded with European research grant. This information, which is available in Appendix 4.2, was included in the PD enrolment form. A statement that their participation would eventually contribute to a PhD dissertation was made during the first week of the course. Similarly, in Case 2, teachers were given a sheet with an invitation to the research, which contained information about its objectives, process and expected results, as well as an email address where they could ask any questions (see Appendix 4.3). In this information sheet they were given a link to a consent form. The form contained a declaration

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5 Available at https://docs.google.com/forms/d/e/1FAIpQLSeFC5VnAmbSdssMEuoYGvKKjAKenamSpasIsvKuxWnf5UqitA/viewform
that they a) meet the requisites to participate in the investigation, b) have read all the 
information about the research, and c) have been informed that they can abandon the 
research at any moment and without having to give any justification. Moreover, the form 
included a declaration of their compromise to record one of their lessons with video, as well 
as personal data such as first name, last name, email address, and ID number.

2.7.2. Role of the researcher

The researcher reflectivity is a common topic to be considered when developing educational 
research, as expressed by most authors in the field of research methods. This term refers to 
the researcher being aware of and openly discussing their role in the study (Creswell, 2012). 
The researcher reflectivity is of utmost importance in ethnographic research designs, where 
the researcher becomes involved in the reality under study in a substantial way, and / or 
during a long period of time. The present research, although it does not correspond to the 
ethnographic design, uses case study design, which has been considered as part of 
ethnographic research. On this basis, this subsection describes how the author of this 
research (hereafter "I") was involved in it.

As explained in Chapter 1: Introduction and research objectives, I conducted this study in 
the context of an educational intervention aiming at having students learn and discuss SSI in 
science lessons. The intervention was part of an overall strategy known as the Engaging 
Science project, which aimed to contribute to Europe's objective to engage citizens in 
research and innovation. This intervention, in which I was a direct participant with a contract 
as a research assistant, had its own goals and development. From the beginning of the 
project, I was involved in the design and implementation, including actions to disseminate 
the Engage materials, as shown in figure 22 below.

Figure 22: Actions in which I participated to disseminate the Engage materials
I was also one of the facilitators of the online Professional Development (PD) course that constitutes one of the cases of this investigation (see figure 23 below).

![Diagram](image)

**Figure 23**: Screenshot of one of the online PD courses that I facilitated

In parallel to being involved in this intervention, as a result of a review of the literature and the knowledge available about the application of SSI in science education, I identified a problem in educational research, namely the characterisation of teachers' delivery of SSI-based instruction as an educational innovation. This research problem has its own goals and objectives, which are independent of those of the Engaging Science project. Therefore, the educational intervention provided a context to investigate the research problem, where the research was performed sometimes in parallel and other times coinciding with the project tasks. For the purposes of this dissertation, I enhanced the understanding I obtained from the project by following more closely two groups of teachers.

To sum up, as an educational innovator I had a role, and as a researcher I had my own research interests, which were agreed with the PhD supervisor, who was the main researcher of the Engaging Science project. This approach is seen an asset in this study for several reasons. First, educational intervention is a good opportunity to analyse innovations in formal education settings. Second, in qualitative research, the researcher being an active participant contributes to gaining a rich understanding and a "within" perspective toward the ultimate objective of the investigation, which is to understand the meanings that subjects or participants attribute to a reality as part of a cultural context.

Nevertheless, the fact that the researcher is also a participant in the research requires to provide some context about the person observing this reality. This context will help to understand its conclusions. To that purpose, my training, my professional experience and my values are described as follows, to explicit how they influence the way I look at this reality.
I consider as initial training the higher education that granted me access to the doctoral programme. I have an undergraduate degree in Media. Such academic degree holds a socio-cultural perspective to the phenomenon of communication, and draws from disciplines such as sociology or semiotics. This training might have played a role in certain choices made in this investigation. For example, the choice of the interpretivist research paradigm, or the choice of using the words of teachers (texts) as the main source of data. Texts do not have a single way to be interpreted, but they depend on the culture (Cohen et al., 2007). I also hold a postgraduate degree (Masters' of Science) in Cognitive Systems and Interactive media, also from Universitat Pompeu Fabra, in Barcelona (Spain). My Masters' thesis, which was a science dissemination activity at the Science museum, gave me the experience and the opportunity to start my career in the field of science dissemination and citizen engagement in science.

The aforementioned education and my professional experience were key in my transition to a full-time research assistant at University of Barcelona, college of Education. As part of the Research group on virtual teaching and learning (Grup de Recerca Ensenyament i Aprendentatge Virtual), which is a quality-recognised research group, I managed different research projects focusing, among others, on educational intervention and innovation in science education. One example is the project Science Center To Go\(^6\), which promoted the use of Augmented Reality (AR) for science education. Another is the Pathway project\(^7\), about Inquiry-Based Learning (IBL) in science education. Those projects mostly focused on in-service teacher training.

To sum up, the researcher point of view that I adopt in this investigation can be described by a social outlook to the phenomenon of education, as part of a society that is shaped by its culture and values. It focuses on classroom dynamics that involve the teacher and the students as participants of a teaching and learning situation that is characterized by helping students to develop basic competences in science. Although my initial training belong to different fields than secondary school teaching on experimental sciences, I have training and professional experience that is relevant for secondary school science teachers' initial and continuing education, such as communication, educational innovation and research, and continuing professional development.

\(^6\) [http://www.sctg.eu/]
\(^7\) [http://pathway.ea.gr/]
3. Data collection and analysis process

One way to understand the process of developing an PhD dissertation, as an educational research, is as a sequence of three main steps:

1. Design/ plan the research: consists of identifying a research problem
2. Field work: consists of applying the plan established. Collecting and analysing the data
3. Communicate the results of the study: involves writing the dissertation

The present section elaborates on step 2: field work. This process consists of gathering the information from the participants, and analysing it according to the research dimensions, categories and sub-categories defined in the interpretive framework (see chapter 2: Theoretical framework, section 5). In this research this process was broken down in the following steps:

1. Gaining access
2. Collecting the data
3. Analysing the data
4. Interpreting the data

A definition of each of these steps, as well as how they were carried out in this specific study, are provided in sections below.

3.1. Gaining access

Access to the participants is key to successfully complete an investigation. The access to participants in this research was through the Engage materials. Participants were attracted to the ready to use, free of charge, materials to teach current SSI that were relevant at that time, such as the Ebola virus, or the increase of popularity of electronic cigarettes. These resources were promoted through a dissemination strategy that included emails to teacher networks, associations and individual teachers, as well as posts in teacher websites (see figure 24 below).
Social networks, mainly *Twitter*, were used to gain access to the participants in this research, as it is considered that the innovative teachers, or those who are interested in improving their practice and keep up with new pedagogical developments are known to be active in it. The information was distributed to accounts that teachers follow, such as the support centres for educational innovation and research (see figure 25 below). Through the emails that teachers facilitated in the website to download the Engage materials, they were invited to the interventions that constitute the two cases in this investigation.
This dissemination strategy also involved face-to-face events such as teacher fairs in big cities across Spain, including Barcelona, Sevilla and Madrid, and workshops, which took place mainly in highly populated cities such as Madrid and Barcelona. As an example, figure 26 below shows pictures of the Scientix conference, which took place on the 24th of October, 2015 at the Science Museum of Alcobendas (Madrid).

Figure 26: Dissemination events to gain access to the participants in Madrid

Other, online dissemination events took place, for example with Spanish teachers who are part of eTwinning, which is a network that facilitates exchange among teachers from different countries. A talk hosted by Mr. Rafael Montero, from school Colegio Corazón de María in Gijón (Spain), was given on the 10th of December, 2015. The talk was disseminated on Twitter as well (see figure below).

Figure 27: Dissemination of the eTwinning talk on Twitter
3.2. Collecting the data

After gaining access to the reality being studied, the next step is to collect the data. This step consists of gathering the raw material that is necessary to answer the research questions. According to the plan, the data for this study was collected through the data collection sources over a period of time lasting from October 2015 to November, 2016.

In case 1, since the interaction with teachers in the PD was mainly online, all the relevant data was collected in a digital form. In this case the open ended questionnaire was delivered as questions in the online discussion forums, as well as with assignments (see figures 28 and 29 below). This strategy is known to increase the probabilities that teachers respond to the questions or provide the necessary data.

![Figure 28: Answer from a teacher to one item of the open ended questionnaire in a discussion forum (case 1)](image)

![Figure 29: Contribution from one teacher to the online forum](image)

As a recognition of their participation in this research, teachers were rewarded with a certificate of completion, and free access to all the Engage materials that they could use in
their lessons. The data of this case study was collected through two editions of the same PD course. Course A took place between October and November 2015. Course B took place between February and April, 2016.

Teachers' outlines of the lessons were obtained as assignments in the PD, sent by email to the PD facilitators. They included text from an email and attachments, which could be in the form of text files (.doc, .pdf or similar), and presentations (.ppt or similar). An example of one teacher is provided in figure 30 below.

![Figure 30: Excerpts of an assignment from a teacher, in Spanish (case 1)](image)

Last, the reflective diaries were obtained in the same way as the outlines of the lessons. They were in text format, and one example is provided in figure 31.

![Figure 31: Excerpt of the reflective diary sent by a teacher](image)

Additionally, some teachers provided photos of the implementation of the Engage materials in class (see figure 32 below).
As part of the reflective diaries, teachers provided examples of the materials they adapted or developed for students, which include presentations and other materials for students, such as information about the scientific content behind the SSI, or extra exercises (see figures 33 and 34 below).

Figure 33: Excerpt of two slides of the presentation sent by one teacher, which was used in a lesson based on the Engage material "Chocolate money"

Figure 34: Presentation material (left) and supporting materials (right) that one teacher used in the lesson based on the Engage material "Ban the Beds"
Some teachers provided examples of student learning products, as it can be seen in figure 35 below.

![Image of student learning products](image)

**Figure 35**: Student learning products sent by one teacher, created in a lesson based on the Engage material "Eat insects" (in Catalan)

For case 2, the data was also collected integrally in a digital way. Teachers filled in the open ended questionnaire before the lesson via an online form (see Appendix 3.1.2). Then, they implemented the Engage material as part of a lesson and they recorded a video of the whole lesson. The video pointed to the blackboard, thus the teacher was visible most of the time, whereas students give their back to the camera. Teachers sent the videos through an online digital file sharing system. After that, teachers filled in their reflective diaries through another online form (see Appendix 3.2.2).

![Images of teachers implementing Engage material](image)

**Figure 36**: Still frames of the videos of two teachers implementing an Engage material in a lesson (case 2)
3.3. Analysing the data

The process of data analysis and interpretation is very important in qualitative research, because it bridges the gap between the raw data and the conclusions or knowledge extracted to answer the research questions. More specifically, the goal of the stage known as analyse and interpret data is to look for the meaning that can be extracted from the data.

Following similar studies in the field of SSI-based instruction, it was decided to use a computer-assisted qualitative data analysis software (also known as CAQDAS or QDAS) to support the step of data analysis and interpretation. The computer software was considered as suitable because the data collected was already in a digital form, which facilitated managing it. Moreover, CAQDAS allows for a faster, more efficient management and processing of the data, look for patterns than other paper-based solutions. This choice, however, was made from an awareness that the computer software is just a tool to perform the data analysis, based on a clear strategy that is independent to the usage of the software (Creswell, 2012).

There are several computer software available for qualitative research. After considering several CADQAS, Atlas.ti was chosen as a frequently used tool in social science research and in educational research in particular that fit well the needs of this study. The software was used with a student license. The data analysis process started with version 7 of the software, although throughout the development of the process, the software was updated to version 9. All the data analysis was performed in the same project on a Macintosh OS computer (see figure below).
More specifically, first for case 1 and then for case 2, the step of analysing the data was divided in the following sub-steps:

- Preparing the data
- Reading through the data
- Coding and analysing the data
- Structuring narratives to describe the contents

These steps were followed for each of the two cases in this research.

### 3.3.1. Preparing the data

Preparing data is the first step in data analysis and interpretation, and it aims to making the data ready for being analysed. This is necessary when more data than what is needed for the investigation has been collected, when the data collected is mixed with other data, or when the data needs to be processed in terms of content or format before it can be analysed. The latter is the case of this specific study because it is set in the context of an educational intervention, which has its own goals, and are separate from those of the investigation.

The data preparation step started with creating two projects in *Atlas.ti*, one for case 1 and another for case 2. In case 1, the data was collected through the online Professional
Development course. The forums containing the answers to the open ended questionnaire were exported from the EDX platform into .doc or .pdf files. One file was created for each forum and it was given a unique ID. For example: the document named "2015_S1_FO Opinion3EModel.docx" includes data from the 2015 PD course (2015_), specifically from week 1 (S1_). The document includes the answers to a forum (FO_) about one item in the open ended questionnaire, namely "What's your opinion about the 3E model?". The outlines of the lesson and reflective diaries were collected as weekly assignments in the course. Teacher submissions to each assignment were exported into an individual document in .doc or .pdf file. Therefore, for each assignment there was one document with the submissions from all teachers. The code was similar to the documents about the open ended questionnaire, for example: "2015_S3_AS_Implement&reflect.pdf".

In case 2, three documents were created for each teacher. One document was the export of the answers to the open ended questionnaire that they responded before the lesson, which was administered using Google Forms. This document includes an export of both the items of the questionnaire and the teacher responses. The name of the document in Atlas.ti includes the teacher ID, and an acronym for "Lesson preparation". For example, for teacher 1, the document name is "T1-LP.pdf". Another document was the reflective diary, which was also administered through Google Forms. Following the same process and naming, the document is named "T1-LR.pdf". A third document was created for the lesson observation, by teacher. Following the same example, for teacher T1 this document is named "T1-OB.pdf". The full list of documents, for both cases, is available in Appendix 5.1).

The following table provides an account of the number of responses that were obtained for each data collection strategy in this investigation.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-ended questionnaire</td>
<td>52</td>
</tr>
<tr>
<td>Reflective diary</td>
<td>54</td>
</tr>
<tr>
<td>Triangulation: teachers' outline of lessons with the Engage materials</td>
<td>33</td>
</tr>
<tr>
<td>Triangulation: lesson observation</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 4: Number of responses obtained for each data collection strategy

As part of preparing the data, a very important task took place, which is to discard the data from participants who, despite having participated in the project and having filled in at least
part of the data collection sources, did not meet the criteria to be included in this research (see section 2.3 above).

Also as part of data preparation, in Atlas.ti I assigned a unique code to all the data that belonged to the same teacher in each case. Each teacher had a code starting by a number indicating what case they belong to (1 or 2), then the letter "T", and a number. For example, the code "1T45" refers to Teacher 45 from case 1. The numbers were assigned by alphabetical order, by surname. This code does not create any hierarchy nor order between the participants. Its only purpose is to give a unique identification (ID) to each teacher and preserve their identity. The teachers who compose case 1 are the following: 1T3, 1T6, 1T9, 1T10, 1T11, 1T16, 1T17, 1T18, 1T19, 1T22, 1T24, 1T31, 1T35, 1T36, 1T37, 1T38, 1T40, 1T42, 1T43, 1T44, 1T45, 1T46, 1T48, 1T52, 1T54, 1T56, 1T57, 1T59, 1T60, 1T63, 1T64, 1T68, 1T79, 1T84, 1T88, 1T89, 1T90, 1T91, 1T92, 1T95, 1T96, 1T101, 1T103, 1T108, 1T109. The teachers who compose case 2 are 2T1, 2T2, 2T3, 2T4, 2T5, 2T6, and 2T7.

Following the example of T45, 14 fragments of text belong to this code. The teacher with the lowest number of codes has 2 codes, whereas the teacher with the highest number has 18 codes. Nevertheless, a higher number of codes does not necessarily indicate a higher participation, involvement in the course or that more data is provided by this teacher. This aspect depends, rather, on the length and quality of these interventions.

3.3.2. Reading through the data

When the data preparation step was completed, the process of reading through the data started. This involved taking a look at the data as a whole, in order to become acquainted with it. This process allows to start to grasp the entire sense of the data, as well as parts where there is more data, worth looking into further.

3.3.3. Coding and analysing the data

The stage of coding and analysing the data consists of the actual abstraction from raw data to knowledge. The main tool that was used for representing the data is codes. The first step in the coding task was to code assign a teacher code to all the data that belonged to that teacher, across the documents in Atlas.ti.

Afterwards, the coding process started. An initial code list was developed, which represents the three-dimensional interpretive framework of SSI-based instruction that was determined
in Chapter 2: Theoretical framework. The framework was based on the review of the literature, which was thought to accurately represent SSI-based instruction as an educational innovation, and it is composed by three levels of hierarchy, namely a) dimensions, b) categories, and c) sub-categories. A sample of the initial list of codes is provided in figure xx below, and the whole initial list of codes is available in Appendix 5.2.

<table>
<thead>
<tr>
<th>Dimension 1: Objectives of SSI-based instruction</th>
<th>Dimension D1</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Contribute to developing scientific literacy</td>
<td>Contribute to develop sci. lit.</td>
</tr>
<tr>
<td></td>
<td>Explaining phenomena scientifically</td>
</tr>
<tr>
<td></td>
<td>Evaluating and designing scientific inquiry</td>
</tr>
<tr>
<td></td>
<td>Interpreting data and evidence scientifically</td>
</tr>
<tr>
<td>o Teach scientific knowledge</td>
<td>Teach sci. knowledge</td>
</tr>
<tr>
<td></td>
<td>Content knowledge</td>
</tr>
<tr>
<td></td>
<td>Procedural knowledge</td>
</tr>
<tr>
<td></td>
<td>Epistemic knowledge</td>
</tr>
<tr>
<td>o Conveying the interdisciplinarity of knowledge</td>
<td>Conveying the interdisciplinarity of knowledge</td>
</tr>
</tbody>
</table>

Table 5: Sample of the initial list of codes

The process of coding consisted of reading through the data and applying the corresponding codes for case 1 and then for case 2, in two separate Atlas.ti projects. This process was iterative, until data saturation was reached.

The coding process was a combination between deductive and inductive. It was deductive because the information was coded according to the predetermined list of codes. At the same time, new codes appeared. These codes, however, represented smaller units of information within an already existing code from the list. For example, in dimension "D2) Components of SSI-based instruction", category "Techniques to discuss SSI", sub-category "Group discussion", different codes emerged, including "establish rules", "facilitate discussion", and "teacher role neutral", among others. These codes provide information that was collected in this research that is valuable to the extent that it identifies themes that concern the specific component of SSI-based instruction known as group discussion. As a result of the coding
process, the initial code list was complemented with more codes, and a final code list was obtained.

Moreover, it is common in qualitative research that the coding system is flexible during the data coding process in order to best bridge the gap between the data and the research constructs. According to Cohen et al. (2007), "some codes that are used in the early stages of coding might be modified subsequently and vice versa, necessitating the researcher to go through a data set more than once to ensure consistency, refinement, modification and exhaustiveness of coding" (p. 470). As part of this process, important decisions were made about key codes that were used in the research. For example a decision had to be made about the code describing the "objective" or "purpose" of the pedagogical use of SSI-based instruction, seeing that in some cases, these words represented student learning goals, and in others it described teachers' personal goals for the lesson. In this regard, it was decided to assign the information to the research dimension that was most representative.

Last, in order to reflect the hierarchy between the codes representing dimensions, categories and sub-categories of the interpretative framework, code nesting was used in Atlas.ti. Code nesting allows the same piece of text to have more than one code, embedded in each other. As shown in figure 38 below, a single fragment of text has been coded with four codes. From those codes, two of them are at a higher level of hierarchy, namely the teacher ID (in this case, 1T103) and the research dimension (in this case, dimension D1: objectives of SSI-based instruction). The same fragment of text is coded with three more codes. One code is "Contribute to develop sci. lit.", which indicates that this text is about the category "contribute to develop scientific literacy". Because this category belongs to dimension D1: objectives of SSI-based instruction, it is nested in the code for that dimension. Nested in the code "Contribute to develop sci. lit." is the two scientific competences that this teacher is talking about.
3.4. Interpreting the data

When the process of gaining access, collecting the data and analysing the data is completed, it is possible to move on to the last step, which is data interpretation. Data interpretation involves establishing relations between the results found from the empirical data and the current state of knowledge regarding the problem studied. While establishing these relations, the study may confirm, contradict or add further detail to existing knowledge about SSI-based instruction.

In this study, this stage involved going away from the research dimensions and going back to the research questions that guide the research, as well as answering them in the most precise way as possible.

The process of interpretation followed the technique known as content analysis. This technique relies in reading the data in its original format (text, images, ...) in a systematic and objective manner. More specifically, this study follows content analysis of open-ended data, as per the following steps (Cohen et al., 2007):

1. Generating natural units of meaning
2. Classifying, categorizing and ordering these units of meaning
3. Structuring narratives to describe the contents
It is worth noting that this is not a sequential, but a stage model, where it is usual to repeat one stage if needed. How these stages have been carried out in the present study is explained as follows.

### 3.4.3.1. Generating natural units of meaning

The first stage in interpreting the data is to generate natural units of meaning. The natural units of meaning in this study are sentences. Sentences are considered useful indicators of how teachers deliver SSI-based instruction. Since sentences are made of words, words are important units of meaning. As an example, in research dimension 1, when teachers talk about the science curriculum, they might refer to "scientific knowledge", "scientific competence", "scientific skills", or use other terminology. These words are not just different ways to refer to the same thing, but according to the interpretive framework, they represent teachers' different interpretations of important aspects of SSI-based instruction. However, although eliciting these different views even at the "words" level is precisely one of the objectives of the present study, these words belong to the main unit of meaning, i.e. sentences, because they need other words, and the context of the sentence, in order to be interpreted so that they are useful to answer the research questions. For example, a sentence is needed for a teacher to express what they understand that a dilemma is in SSI-based instruction.

Working with sentences as units of meaning, this stage involved a first round of analysis that allowed to identify themes for further interpretation. At this stage, this study followed the strategy known as "working the data from the ground up". This is one of the four strategies according to Yin (2014) and it is an inductive method. This method is based on pouring through the data and identifying emerging concepts and patterns that are further explored.

The opposite approach is known as "working the data from the ground up", or "relying on theoretical propositions" (Yin, 2014). This strategy was considered for the present study, and it would have implied to build hypotheses for each research dimension, for example "teachers have a content knowledge-based interpretation of SSI-based instruction". These hypotheses would guide the analysis, for example by focussing the analysis in describing that vision. However, the purpose of this study was not to prove existing theories wrong, but to describe a reality of a problem that is not sufficiently understood.
3.4.3.2. Classifying, categorizing and ordering these units of meaning

This stage involves classifying, categorizing and ordering the units of meaning into themes. The emerging themes were identified as a result of a process that is inspired in a practice known as quantitative analysis of qualitative data. This technique "counts and logs the occurrences of words, codes and categories. From here statistical analysis and quantitative methods are applied, leading to an interpretation of the results" (Cohen et al. 2007, p. 470). In this study, quantitative descriptive analysis was performed, by counting the times that each code appeared. This method enables to identify the predominant views about a theme. A sample of the frequency count of the codes regarding "Assessment of student learning" is provided in Table 6 below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment: Exam</td>
<td>1</td>
</tr>
<tr>
<td>Assessment: Observe students</td>
<td>6</td>
</tr>
<tr>
<td>Assessment: Peer-assessment</td>
<td>1</td>
</tr>
<tr>
<td>Assessment: Process</td>
<td>2</td>
</tr>
<tr>
<td>Assessment: Self-assessment</td>
<td>5</td>
</tr>
<tr>
<td>Assessment: Student products</td>
<td>7</td>
</tr>
<tr>
<td>Assessment: Teacher notes</td>
<td>1</td>
</tr>
<tr>
<td>Assessment: Unspecified</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 6: Frequency of the codes regarding "Assessment of student learning"

The process of classifying, categorizing, and ordering units of meaning also involved finding relations between codes in each research dimension. These relations can be of different kind, mostly association, and cause and consequence. One example is the code "student role: proactive". Teachers refer to students at different points and in different ways, and they refer to them more when talking about specific pedagogical techniques such as group discussion rather than in other research dimensions. It was decided to create a code about students, but in general terms, in a transversal way as opposed to specifically for dimension 2) that is where the technique group discussion belongs.

Another example is in the codes under "challenge". These codes represent what teachers find as challenges to the application of SSI-based instruction in their contexts. They could be referring, however, to the group discussion (Dimension 2 - components of SSI-based
instruction), or to one of the categories in Dimension 1 - objectives of SSI-based instruction. This association was made with the function of Atlas.ti called "network". This function allows to visually represent relations between codes. This choice was informed by the realisation that teachers referred to the concepts that are relevant for this research at different points independently what they were asked about or when.

![Diagram of relations between codes](image)

Figure 39: Example of the relations between codes using the function "network" regarding the analysis of group discussion

### 3.4.3.3. Structuring narratives to describe the contents

The stage after classifying and categorising the data into the themes identified allows to go one step further in the process of abstraction to provide useful insight about the constructs that this research aims to providing knowledge about. One way to do so is by making assertions (Erickson, 2012). These assertions are self-contained, and excluding from each other, to accurately represent and contribute to the constructs that were investigated. Consequently, the number of assertions that are made indicate the depth of understanding that was obtained from the data. Some of the assertions done at this stage were the following:

- Teachers agree with the view of science as a very socially relevant activity, with an impact in collective and individual lives
- Teachers see science as involving different disciplines and processes that go beyond "strictly scientific" rules, science is subject to the ethical rules of the societal context in which it is developed
- Teachers agree that science and scientific thinking is a good way to be critical in a society where it is very easy to make assertions or communicate ideas massively
- Teachers' need to combine "what must be taught" according to the curriculum, and what students are curious about or might be more motivated to learn
- The importance of the size of the group and student characteristics to carry out SSI-based instruction

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• The difficulty to have students participate, engage or get involved in SSI-based instruction

• Teachers' concern about how much time SSI-based instruction involves, therefore threatening their plans to deliver an already very dense curriculum

• Teachers generally work on their own or in some cases in collaboration with colleagues from similar disciplines, but only very rarely with teachers from non-STEM disciplines, or other staff in the school: head, manager, etc.

• Teachers' are satisfied with the results of SSI-based instruction, especially in terms of getting students engaged in their learning

• Teachers are not very confident about their skills to design and carry out an effective SSI-mediated T&L experience
CHAPTER 4

RESULTS
Chapter 4: Results

Following the multiple case study research design of the investigation, two cases were analysed using the qualitative analysis software *Atlas.ti* (version 1.0.48) and the procedures determined in Chapter 3: Method. The data was organised and coded following the three-dimensional framework of analysis of SSI-based instruction, namely a) objectives of SSI-based instruction, b) components of SSI-based instruction, and c) resistance to SSI-based instruction.

This chapter presents the results of the analysis. It is divided in two main sections, one section per case. For each case, the main tendencies that were found were described in detail, as per the three research dimensions. Quotations from the data collection sources are provided to illustrate the statements, followed by the code of the teacher that the quotation is from.
1. Results for case 1

The results for case 1 of this study are presented in this section. The data for this case was collected and analysed following the procedures established in Chapter 3: Method of this dissertation.

1.1. Results for dimension 1) Objectives SSI-based instruction

Teacher responses to the data collection sources that were determined for this case were analysed from this point of view, according to the categories that were determined in the interpretative framework. As a result of the analysis, trends within each category of this dimension can be observed. What follows is a short summary of each category, and the results obtained for each.

1.1.1. Contribute to the development of scientific literacy

Following the interpretative framework, the usefulness of SSI in helping students develop the three competencies of scientific literacy has been analysed. These are: 1) Explaining phenomena scientifically, 2) Evaluating and designing scientific enquiry, and 3) Interpreting data and evidence scientifically. The main results are presented below.

1.1.1.1. Explaining phenomena scientifically

This competence is described as the ability to “recognise, offer and evaluate explanations for a range of natural and technological phenomena” (Organisation for Economic Co-operation and Development, 2017), p. 22. The data analysis revealed the relations that teachers in case 1 establish between SSI and this scientific competence.

Teachers see SSI as an example of a school’s task to “provide” the knowledge to understand the reality around us. One teacher articulates this idea around the construct “scientific culture”, which helps to “understand the reasons explaining the phenomena around us” (1T17). Another example is from a teacher who says that “At a competence level, it is expected that students are able to resolve problematic situations and questions that require the deployment of scientific theory (variables, concepts, and relations between concepts)” (1T103). Regarding the sinking islands issue, a teacher says that “It shows, with a real and very clear example, the consequences of an overall rise in temperature due to certain human activities” (1T56).
Scientific explanations will mostly be focused, according to these teachers, in phenomena from students’ daily lives: “Often students become interested and pose scientific topics that they are not able to resolve, precisely because they do not relate science knowledge with life; they see it as separate, disconnected things. For this reason, I think working with SSI that show this interdependency is very interesting” (1T22). Similarly, one teacher states that “[One of my goals is to] help [students] see that what we study in class is important for ‘real life’” (1T11).

In other words, teachers perceive teaching SSI as a way to make students aware of the need to make decisions precisely about these SSI, as problems that concern them or their community. From teacher comments it can be inferred that knowing the scientific explanations of certain phenomena will make students act differently and bring about change based on scientific knowledge, as opposed to other criteria. As expressed by one teacher: “When we read the competences in the curriculum, we can see that scientific or technological knowledge must be used by students to communicate and make decisions” (1T22); “In my case, educational legislation calls for student development of basic competences (...) which must enable inquiry, collaborative work, making decisions, etc.” (1T24).

One example can be found in a teacher’s report on using material about the issue of “Text neck”. This material concerns a new neck condition associated with using a mobile phone, texting in particular. This teacher states that “I have presented them tips to monitor their postures and the efforts we can make in our daily lives to promote a healthy lifestyle and avoid potential injuries or pathologies” (1T17). A similar example is found with the material “Ban the beds”, which provides a scientific explanation about how and why UV ray booths tan skin, with respect to which one teacher commented that “[it] can potentially improve their protection when they are exposed to sunlight” (1T10). About the Big Bag Ban issue, one teacher says that it “is interesting regarding the knowledge that [students] could develop and hence informs future responsible decisions” (1T17).

More specifically, certain phenomena or topics are of special importance for education at the time that this research was developed. The PISA 2018 contexts were chosen as a reference to interpret the data. In terms of the context a) Health and disease, some of the issues that teachers mention are: vaccination (1T54), contraceptives (1T9), Genetically Modified Organisms (GMO) (1T36), or molecular genetics (1T36). Regarding the context b) Natural resources, one teacher lists as potential topics “Discussing energy sources, the ‘sun tax’, who has power over those energy sources” (1T56). For the context c) Environmental quality, one
teacher states that “climate change… has a lot of potential with teenagers” (IT56). Finally, with respect to the context d) Frontiers between science and technology, teachers mention topics such as: weapons of mass destruction (IT31), artificial organs and tissues (IT38), challenges faced by big research projects such as CERN (IT17), bringing extinct species back to life (IT48), and stem cell research (IT18).

### 1.1.1.2. Evaluating and designing scientific enquiry

Teacher associations between SSI and the scientific competence 3) Evaluating and designing scientific enquiry were analysed. This competence involves “Describing and appraising scientific investigations and proposing ways of addressing questions scientifically” (Organisation for Economic Co-operation and Development, 2019), p. 101.

There is an emerging trend in the data, where the SSI proposed in the Engage materials are seen as topics worth researching in a scientific way that students, teachers or the curriculum have not investigated before. A few teachers use the concept of “question”: “Students must be able to ask questions about what they observe and try to give an answer in a scientific way” (IT44); “I would love to know how to apply these methods in the classroom and teach students to ask themselves questions, and think” (T47). “I think it is very important to spark students’ curiosity and motivate them to keep asking themselves questions” (IT48). Another teacher brings it down to the subject s/he is teaching: “In my subject, Biology, it is essential that students are curious and do not overlook the phenomena that they observe”. (IT44).

Teachers emphasise evaluating scientific inquiry as a way to solve the tendency they have observed among students to accept any information they receive as true, in what seems to be an implicit assumption that that not all seemingly scientific data about SSI are scientific. As expressed by one teacher: “I am interested in helping my students learn to think by themselves, and of course, to question the information they receive” (IT54). These teachers highly value this competence, which they articulate around the need to know how scientific or seemingly scientific knowledge has been produced in terms of objectivity, rigour, etc. This will help students judge to what extent a given piece of information is true or reliable, etc. based on knowing the scientific procedures that produced it.

### 1.1.1.3. Interpreting data and evidence scientifically

Teacher interpretations of the contributions of SSI to the development of students’ scientific competence 2) Interpreting data and evidence scientifically were also analysed for case 1.
This competence is defined as the ability to “analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions” (Organisation for Economic Co-operation and Development, 2017).

This competence involves different processes, and teachers associate SSI particularly with the process of abstraction from data to knowledge, which is part of this competence. One teacher highlights the need for students to be able to “Establish relations between natural phenomena, analyse graphs and draw conclusions, establish relations between concepts, …” (IT45). As another teacher puts it, “Competences explicitly describe students’ ability to reason, interpret, infer…” (IT11). Similarly, another teacher states that “From the scope of scientific competence, I think one of them could be addressed in particular [with SSI], which is: to become autonomous, effective, critical and reflective people regarding selection, processing and deployment of information and its sources, in different supports and technologies” (IT31).

A tendency was found among teachers in case 1 to deem this competence useful when assessing the scientific quality of evidences or arguments that are given in public discussions or in discussions among people who are not scientists, about scientific issues. For instance, one teacher mentions that “Ethical discussions about genetics (…) are not grounded scientifically. There are too many reasons derived from Christian morality which are not scientific. It is important that students understand that these are two different levels of reasoning and that in science class we need to use evidence-based arguments, because that is the scientific way of proceeding” (IT9). Another teacher brings up the example of the World Health Organisation message about the relation between certain types of meat and stomach and colon cancer. In reference to the relation between the evidence provided and the statements or conclusions made on the basis of such evidence, she mentions that: “Evidences are poor because they refer to populations that abuse these products” (IT38).

1.1.2. Teach scientific knowledge

This section reports on the results regarding the affordances of SSI to achieve the objective of teaching scientific knowledge, according to data from case 1. As expressed in the conceptual framework, scientific knowledge allows students to develop the key competences in the curriculum. The following subsections highlight the main results regarding the knowledge that formal education aims to help students develop and which teachers relate to SSI. Data was analysed according to the three types of scientific knowledge, namely: a)
Content, b) Procedural, and c) Epistemic. Teacher responses have been organised and are presented below.

1.1.2.1. Content knowledge

As a result of the data analysis, it is possible to identify trends in teacher usage of SSI, understood as contexts to teach content knowledge in case 1. Teachers agree that SSI are useful to work on content knowledge. For example, teacher 1T9: “I think that in these types of activities, we need to stop for a moment (…) and work on the curricular content” (1T9). The same teacher states that: “if we address the content when it is needed to solve the problem, that is, during instead of before or after the process, it will make more sense to students” (1T9).

Teachers tend to see SSI as useful tools to teach abstract content, as in concepts, or scientific facts or theories. According to the teachers, formal education presents scientific content in an abstract way, this is, disconnected from problems that students can understand or relate to, and therefore those they care about or feel compelled to make the effort to learn about. As one teacher puts it: “These types of proposals are very motivating, both for students and for me. In the past I have found myself teaching something that was so out of context that even I questioned whether it made any sense to teach it” (1T11); “Approaching the study [of forces] using SSI brings the content near students’ reality and gives them a sense of usefulness” (1T31). In reference to the material “Is there life on Enceladus?”, one teacher highlights that “It helps me to put in context all the content we are addressing related to matter and kinetic-molecular theory in a very dynamic way” (1T52). As one teacher puts it: “I find it interesting because it approximates a very theoretical topic with an example” (1T10). “This type of learning is way more interesting and enriching than the classical way of learning, which is based on theoretical concepts” (1T36). “I can’t stop thinking about looking for new strategies so that students (…) find it useful to know things” (1T45); “I think it is a good way to motivate students, to introduce concepts or to strengthen them” (1T48). In reference to the issue “Animal testing”, one teacher proposes “To work on the content of respiration” (1T9), which is abstract content as well.

Teacher emphasis on SSI as a way to teach abstract scientific content in context is especially appreciated to the extent that it establishes a link between the curriculum, or what students do at school, and students’ “real life”: “As a science teacher, I think it is very important that students feel that the science that we teach in class is directly related to their daily life” (1T22).
“Learning for the sake of learning is only feasible in the short term (...); learning is important but as long as they understand its relation with daily life” (IT45). The same teacher says that “for natural sciences, for instance, there is a need to ‘go out to the street’ and with this methodology, students are more likely to know what they are doing and why” (IT45). Some teachers refer to these real-life problems as social problems. For example, one teacher says that “It is necessary to organise learning activities that incorporate the social dimension and ask for solving authentic problems that are linked to a real-life context” (IT108). Another teacher states that “teaching science should not be dogmatic, but oriented to its application in social life” (IT40).

One teacher is slightly more precise by establishing a relation between content knowledge and decision-making: “The most important thing is that when you have to teach a given curriculum or contents, these can be addressed in a diversified manner from some needs that appear or from some challenges that are real or plausible. Especially those that require decision-making” (IT42). Another teacher says that “As stated in the curriculum (...), in the introduction to the subjects of Biology and Geology: ‘usual learning activities do not produce learning outcomes which can be applied to other contexts’” (IT108).

1.1.2.2. Procedural knowledge

Analysing the data collected in case 1 revealed a tendency to see science as developed in collaboration with others, not individually. As expressed by a teacher: “The benefits are many (...), the skills to carry out an inquiry as part of a team, which are now required for professionals” (IT64). In the words of another teacher: “In my case (...), for example, the curriculum defines a series of methodological recommendations: (...) - Present science as an open and interactive discipline” (IT31).

Teachers highlight the uncertainty of scientific data and decisions and that facts are open to interpretation. As expressed by one teacher: “Science is (...) not certain” (IT9), “[this method] is close to the way work is conducted by scientists, who experience lots of uncertainty in their research and especially in the decisions they make” (IT42). Some teachers articulate this idea around the fact that science is a human activity. This means that as such, it is fallible, it does not work like a machine, but there is uncertainty and unexpected outcomes, results or changes that are impossible to control or predict. “Scientific models are contextualised in social and ethical aspects, so making decisions becomes a complex process of argumentation and with a wide range of responses” (IT43).
Some teachers put argumentation at the same level as other activities, which are traditionally associated with scientific activity. Example: “[it] allows students to develop scientific skills such as argumentation and reasoning” (T15); “Determine problems, assess solutions, elaborate arguments, criticise arguments, understand the media, and communicate ideas” (T18). One teacher includes argumentation as part of this process that directly refers to working with statements and making sense of them: “Develop scientific competences: argumentation, reasoning, looking for evidence…” (T37).

The most common view that teachers express in this case is that the process by which scientific knowledge is developed influences the reliability of such knowledge. Teachers imply that the knowledge generated as a result of the scientific process can be trusted to different degrees according to how it was developed. This is articulated around a reflection on the influence of the funding received by a study in order to interpret its results. Some teachers stress the influence of political decisions and especially emphasise the need to know where the funding for a given research comes from. “I think [students] have an idealised view of the pharmaceutic industry and they ignore everything that is behind research and commercialisation of drugs” (T37). This is a type of knowledge that is worth conveying to students as part of a formal education, according to this teacher. In reference to the SSI appearing in the context of recent studies establishing the link between consuming red meat and cancer, one teacher states that “We need to ask ourselves about these studies and about the data supporting these correlations, seeing that we are in a [societal context] of economic crisis and budget cuts” (T38).

1.1.2.3. Epistemic knowledge

SSI triggered teacher reflections about scientific activity as a way to progress, grow or create wealth. Some teachers approach the reflection about the consequences of products of scientific and technological activity from the point of view of the “power” that scientific knowledge can have in social progress. Scientific knowledge, when it is not accessible to the wider public, may pose challenges in society such as equality, social justice, etc. Teachers perceive context-based SSI as a way to address this aspect in class: “There is a very old video from General Motors about hydrogen batteries for cars. It explains how they can even be a source of energy for the house, or energy that you can donate to whoever you want. Well, the thing is that by demonstrating that energy is the engine of the world, and therefore control depends on who owns it, it links the decentralisation of energy sources with new societal models” (T56). For example, in a reference to the LHC particle accelerator, one
teacher asks “Is this type of research worth it? What challenges does it raise?” (T17). Similarly: “[Space exploration] implies a high risk for the astronauts involved. Shall we continue sending people to space? Searching for life on other planets?” (T8). Teachers in this case agree that scientific research should respond to the needs of society. The principle of desirability stands out, and is particularly grounded in the fact that science, as it is developed in our society, has a monetary cost: “Exploration of outer space requires a lot of resources, and does not always offer direct social benefits” (T8); “To what extent should we invest in alternative energies for air transportation, which consumes a lot of fuel?” (T42).

One teacher makes use of a real-world example. According to this teacher, investing in scientific research is worth it, despite the lack of guarantees about its usefulness or effectiveness of its results, because sometimes during scientific research other important discoveries are made: “The topic of the investigation of the Higgs boson is one of those that I propose in working with the students. Even though the boson is what scientists were looking for (there is some evidence that this particle exists), with the technology that has been developed at CERN to improve accelerator detectors, it has been possible to build very useful devices for medical diagnosis, for example, in obtaining images (positron emission tomography, PET). Moreover, because of the enormous challenge of information management CERN faced, the web [the internet] was designed (without which we would not be doing this course right now) and GRID is in process, which is a new system for sharing information worldwide in a much more powerful way than the web. What seems like a big expense can end up being an essential investment!” (T17).

Another tendency emerging from these teacher statements is that scientific activity must comply with the moral system of the cultural context in which it is performed. Some examples supporting this assertion are: “Research which excludes a discussion of the moral implications of its findings is inhuman” (T40), “[the Engage materials] are an opportunity to apply the ethical and discussion side needed in science within society” (T16); “Since science is not neutral, research, hypotheses, conclusions and publications are not alien to values” (T9); “Addressing the ethical aspects of SSI is also very positive for students, since it is strongly related to what students will find in the future” (T18). Related to this is another trend that was found and that can be expressed around the idea of the consequences of scientific activity described as “playing God”. This has to do with scientific activity as a way of intervening in “naturally occurring” processes, for example creating artificial organs, or genetically modifying seeds. This is a well-known issue related to scientific activity that has
been addressed by disciplines such as scientific ethics. As expressed by one teacher: “The possibility to artificially create a genome and generate new species of bacteria which are able to degrade toxic waste, capture carbon dioxide, etc. raises the question of how these can interact with the environment and with other species. Moreover, the possibility to synthesise more complex organisms invites us to think about the functions that we will assign them and which will be the purpose of their existence” (1T38). Another teacher focusses rather on the dangers for humans associated with experimentation with technologies: “In the days prior to starting the LHC particle accelerator at CERN, the idea began to spread that when it started to function a black hole would be created that would swallow the Earth” (1T17).

Teachers also discuss the idea of science as the “only” way to create knowledge or comprehend the world. Their comments about the group discussion as a way to discuss SSI reveal their understanding of the scientific practice known as scientific argumentation or “strong” justification of scientific claims. One teacher who emphasises this is teacher 1T42: “I think that we should always have the evidence and scientific proof to support the arguments. Science is based in observation, experimentation, and consistency between results and conclusions”. These teachers consider anything that is not scientific as the opposite of a solid argument. Teacher 1T42 also says “I worry that students will get lost in emotional or unsubstantiated ideas, (...) since from the point of view of our subject [science] not everything is valid, [for example] there is the danger of pseudoscience”.

1.1.3. Convey the interdisciplinarity of knowledge

This category evaluates the potential of SSI to contribute to an overall strategy in science teaching to break the boundaries between subjects in secondary school teaching practice. The tendencies identified in case 1 are presented as follows.

Interdisciplinarity, for some teachers, is understood as the connections between what are traditionally known as science or STEM disciplines. For example, one teacher says that “This is suitable for many areas, especially in the fields of science and technology” (1T45). Another teacher states that “In my opinion, it is a good resource because it integrates what could be perceived as different topics and disciplines: chemistry (structure of molecules, density, sublimation), biology (origin of life...), geology (geysers, craters, volcanic activity), physics (reflection of light, gravity...)” (1T11). A similar point of view is expressed by teacher 1T19: “It uses different scientific (biology, chemistry, geology) and technological disciplines in a globalised way”; “I really liked how the activity was set up, especially at the start where the
relation between two scientific disciplines is made explicit, namely biology and physics. Traditionally, we tend to separate those subjects” (IT43). Among the curriculum items that teacher IT31 quotes is “Address contents in an inter-related way, to avoid a compartmented vision about science”. Another mentions “the relation between technology and neuroscience” (IT19). For one teacher, the material called "Chocolate" is good because “it establishes a relation between two knowledge areas: human nutrition and the problem of natural resources” (IT35).

Another tendency is to interpret interdisciplinarity as the relationship between science and other subjects. One teacher mentions the “Possibility to use [SSI] in other subjects” (IT18). References to transversal competence or skills are also made, especially critical thinking: “The most important goal of education is to help to create critical thinkers who can contrast facts and theories and who can progress towards what is yet unknown” (T12); “Science at school should not consist of transmitting a set of scientifically proven theories, but its goal is to educate people who are critical and have the tools to understand the natural world and be able to act in it” (T13); “Most teachers share the idea that the main goal of (public) education is to create citizens who are critical and involved in society” (IT16). Similarly, in a reference to the material “Is there life in Enceladus?”, another teacher says that the material makes use of scientific knowledge “To make a decision that is more social than scientific” (IT19). One teacher conceives the method as a way to help students develop “cognitive-linguistic competence” (IT9).

### 1.2. Results for dimension 2) Components of SSI-based instruction

Dimension 1 of this research analysed the educational phenomenon of SSI-based instruction in secondary school science subjects from the point of view of its purpose, or why these issues should be taught. According to the interpretative framework that was constructed for this study, dimension 2) Components of SSI-based instruction is concerned with how secondary school science teachers deliver SSI-based instruction. The data provided by teachers in case 1 has been collected and analysed. What follows is an account of the results obtained for each component of this dimension.
1.2.1. Methodological approaches: Inquiry-Based Learning

The understanding of the methodological approaches that were determined in the conceptual framework has been analysed for case 1. As stated in the conceptual framework, several methodological approaches can be used to teach SSI. For this research Inquiry-Based Learning (IBL) has been chosen.

As a result of the analysis of this group of teachers, trends regarding the main characteristics of Inquiry-Based Learning have been identified. One is that it is essentially a student-led methodology. Teachers in case 1 link this to being in charge: “It makes students active, it makes them protagonists in the classroom” (1T16); “Classes are more dynamic, where students feel like protagonists instead of just receivers of ideas” (1T64). One teacher refers to “Student implication in knowledge creation” (1T90). Or “The autonomous and active role of the student needs to be reinforced by a wide range of active methods that facilitate their implication and participation” (1T108). Another teacher adds that “The goal is that students learn without direct intervention, without continuous control, but I believe that supervision, orientation and feedback are necessary to achieve significant learning” (1T19).

Another trend concerns student development of knowledge on the basis of evidence about SSI, which is a characteristic of IBL. In particular, teachers in this group compare this methodological approach to how scientists develop knowledge. In the words of one teacher: “[this is] a more natural approach, where science is taught through the scientific method, that is, students build their own knowledge, as opposed to a set of ‘pre-made’ concepts and knowledge for students” (1T18). The same teacher comments that: “I think this course is completely related to the new approach to science teaching, which is more natural, where science is learned through the scientific method, that is, students build their own learning, not as a series of concepts and “pre-cooked” theories” (1T18). Two more teachers refer to this: “The ultimate grounding of this way of learning is the scientific method, and SSI are a good way to practice it” (1T56). Another teacher expresses “the need to provide a learning experience which is (…) focused on understanding how science works, with questions, and experimentation to verify students' own hypotheses and draw appropriate conclusions” (1T35).

The evidences that teachers mention can come from different sources, including peer opinions, ideas or knowledge about SSI. Teachers show their understanding of group discussion as a way for students to develop new knowledge as a result of listening to their
peers, where peer opinions or information constitute evidence about the SSI. This shown in the following statements: “I think it is very interesting that students create their own opinions based on those of their peers; these are the ones that make them question what they thought was certain at the start” (1T6). The same teacher shares an experience: “When I have carried out discussions in class, I found that some students change their point of view in a reasoned way after discovering other approaches to the same question, or when they have done a bit of research on the topic” (1T6). Another teacher proposes to “Give the opportunity to students to create their personal opinion about an idea, as well as see how through the discussion, many times these opinions change as a result of the interventions of their peers. This leads students to take into account the opinions of others” (1T63).

The adaptations that teachers propose to try with Engage materials, which follow IBL, influence how the sequence of stages is interpreted in practice. Teachers add more learning activities, additional resources or more content in different parts of the IBL sequence.

Regarding phase 1) encounter the issue or “Engage”, which is oriented to exploring students’ existing knowledge about the topic or capture their attention (T8). In this phase, some teachers also add more information about the SSI itself (T8, 1T19).

Regarding phase 2) collect evidence or “Extend”, most of the activities that teachers add involve comparing two options, such as the nutrients in insects versus the nutrients in other foods (1T35), or comparing the frequency and energy of natural light (1T43). One teacher added an expert activity (1T37), and two teachers added a “hands-on” experiment. One teacher added an experiment with sugar (1T42), and another teacher shared that “In addition (…), I try to do a laboratory-like activity or one that involves predicting the results (…). For example, in the SSI “car wars” I add a simple experiment to check the thermal inversion that takes place in cities” (1T6). In this phase, some teachers also decide to add more content, (1T10, 1T35, 1T36, 1T43). This may be delivered by the teacher in some cases, or organised as an activity for students. For example: “In order to prepare the debate, we ask students to look for information about the models of the universe in the 16th century that led to conflict” (1T43).

Finally, teachers suggest activities in phase 3) synthesise or evaluate student learning (1T9, 1T19), which correspond to the IBL phase of “evaluate”. This is the case of one teacher, who after the lesson commented as follows: “On the basis of an experiment that we will have done in the classroom, seeing the results I would make groups and ask each of them to
make a conclusion or an explanation of the results. This is a way for them to apply all the knowledge they have developed” (1T45). Another teacher said that “I assume curricular content is addressed as the lesson progresses, and there is no need to explain it before or after. Maybe only a few minutes are needed to clarify some content and at the end of the lesson, a reflection about what has been learned” (1T9).

Some teachers conclude the lesson themselves: “It is essential that the teacher redirects or articulates knowledge after the activity, in order to build and structure the contents and achieve the learning goals” (1T42).

These modifications are not mutually exclusive. One teacher considers both possibilities: “Activity of introduction or synthesis of a learning unit” (1T18), and another one reports that “Sometimes I organise a discussion as a starting point to present a particular activity, and after it I organise it again to see if there has been any change of opinions” (1T43).

1.2.2. Techniques for discussing SSI

This category has been analysed for case 1, as divided into dilemmas and group discussion.

1.2.2.1. Dilemmas

The need for students to take a position is the main reasons why teachers in case 1 appreciate the dilemma as a way to get them engaged with the SSI: “It “forces” them to choose a position about a controversial issue” (1T16). For some teachers, this is also is a way to gather information that could be useful to deliver better, more meaningful lessons. For example, one teacher highlights that “We choose a car according to our priorities, i.e. the environment, cost, the possibility to access electricity, etc. Here is where we can see the personality and different mind-sets of our students” (1T6).

Secondly, the need to make a decision was highlighted as positive: “It’s when students really put into practice their knowledge and skills” (1T17). “I think the possibility to decide about a scientific issue makes it worthwhile [for students] to know basic concepts (…) that otherwise would only stay in the short-term memory” (1T38).

In case 1, two misconceptions about the dilemma were identified. One misconception is the imprecise use of the words “dilemma” and “SSI”. The other misconception is to consider the dilemma only as a process of decision-making on the basis of argumentation.
Several evidences were found supporting the first misconception in case 1. As shown by the words of one teacher regarding GMO: “It is a health-related dilemma (we don’t know its long-term consequences), and an ethical dilemma (is it right to create new living organisms?)” (1T16). Similarly, teacher 1T35 proposes an SSI about the nuclear accident in the town of Palomares, which took place in Spain in the 80s. The way he presents this SSI indicates that this teacher is more interested in addressing political or ethical debate with students about nuclear energy, rather than choosing between different, non-desirable alternatives. As per another teacher’s comment, a dilemma could be used to discuss “The scientific, social, ethical and environmental point of view on the issue of nuclear energy usage” (1T43).

As for the second misconception, teachers mistake the dilemma for the act of making decisions about scientific-related topics, taking into account not only scientific arguments but also social, economic, political, etc. For example, when asked to propose a dilemma, a teacher suggests to “Pose the question of whether [students] would agree to set up a chemistry industry in their town with a positive impact (investment, employment) and a negative one (waste, risks,…)” (1T10) Another teacher mentions previous experiences using SSI in the classroom aimed at helping students understand the actors involved in an SSI and their viewpoints, including scientists, politicians, environmental movements, neighbours and industry, concerning the issue of building a new dam in the town (1T9).

Finally, it was found that teachers may have a biased view when posing a dilemma about an SSI. This bias manifests as black and white dilemmas, or dilemmas that do not really allow for objective engagement with the SSI. Teacher 1T3 is an example: “A few months ago, I saw a report warning about the progressive extinction of bee colonies in Europe. It pointed to the usage of pesticides as the most probable cause. The discussion involves chemical companies and the agricultural industry. Is it sustainable to produce without using pesticides? Which agricultural model would we have? (…)” (1T3).

### 1.2.2.2. Group discussion

The results obtained for case 1 about technique for discussing SSI known as group discussion are presented below.

#### 1.2.2.2.1. Student use of knowledge about the SSI in group discussion

The main feeling in case 1 is that group discussion is valuable not only because students can express their knowledge about different aspects of the SSI in a way that is easy to understand
for their peers. Some teachers express this idea by opposing group discussion and other ways of engaging with the SSI: “[Students] must know the topic to be discussed, because studying a topic for an exam is very different from studying it in depth to be able to have a discussion about it” (1T59). This reasoning is similar to that of the teacher who commented that “Establishing a group discussion brings many benefits, because the student must have absorbed and processed all the content in order to provide arguments and reason through them” (1T109). As expressed by another teacher: “Group discussion is a great resource either to introduce or conclude a topic, because it helps to organise ideas and make sure they are clear enough” (1T79).

Some teachers in case 1 give more importance to students expressing scientific knowledge about the SSI during group discussion. For example, teacher 1T59 stresses that students must “use scientific groundings in the discussion”. Another teacher reports a previous discussion about an SSI where she devoted specific effort to student use of scientific content in the discussion:

“I have used scientific controversies on some occasions, especially phase 1 to involve or motivate. It is often difficult for students to relate their scientific knowledge to the phenomenon or problem that is posed to them. For example, last year it came out spontaneously in one of the 3rd ESO groups during a discussion of whether a woman should have an abortion if she is aware that she is carrying a child with a genetic disease. The discussion was rich but what was hard for them was to redirect the issue towards the more scientific part of the issue” (1T42).

For some teachers in case 1, the added value of group discussion is not only that students communicate their knowledge, but that such knowledge may be challenged by their peers. In their mind, part of group discussion is that students at least consider updating their knowledge about the SSI on the basis of the arguments presented in the discussion. As one teacher puts it: “Students learn to structure their knowledge, elaborate arguments in a scientific way, reason, be flexible, listen to others and be able to decide whether to incorporate or reject alien ideas, as well as reach conclusions” (1T11).

1.2.2.2. Rules of group discussion

The data analysed in in case 1 shows that providing a set of rules before starting the discussion is key, “so that [students] are clear about what is expected from them” (1T11).
The same teacher says that “If it is not well prepared, discussion can be sterile and generate frustration both in students and the teacher” (1T11).

Teachers provide rules regarding different aspects of the discussion: “In some of the discussions that I have already organised, I have learned that before starting the discussion, it is very important that the timings are clear and that a little structure to the group is provided” (1T63). One teacher recalls an experience where “We addressed ethics and values, and we reflected about why we have certain opinions (our opinion is worth as much as the one of the person next to us, and we must not judge it but listen to it (...). We addressed empathy explicitly” (1T103).

The rules for group discussion can be set up in different ways. Some teachers provide this structure to students, for example by having “rules/tips hanging on the wall as a reminder” (1T42). Another vision is more focused on negotiation between the teacher and students, in order to include them. Teacher 1T103 is an example of this: “I think that first, I would ask them how they understand a discussion. I’d write key words on the blackboard, as a kind of brainstorming. On the basis of their ideas about what a discussion is, I’d supplement their definition, and most of all I’d clarify the exact group discussion dynamic or technique that we would use in this case” (1T103).

Information about how to configure groups of students for discussion was gathered in this case. Some teachers make the groups: “I make the groups myself, so that they are diverse (boys and girls, different interests, academic level...), just as society is” (1T16). Other teachers focus on the principle of “comfort” or “good atmosphere”, which in practice means to take into account student preferences when it comes to forming small discussion groups: “The biggest challenge is to achieve a pleasant climate, and to achieve that, group creation is key (...). It is necessary to consider all types of students, and create groups where all of them feel comfortable with participating and expressing their opinion, which is sometimes very complicated. (...) Sometimes, I have let students choose their groups, accepting the risk that some students may be marginalised” (1T63)

1.2.2.2.3. Managing group discussion

Teachers in case 1 recognise that their role in preparing and foreseeing problems is crucial to the success of group discussion: “I have had a few negative experiences with group
discussion, because it didn’t work as I expected. It was my mistake, because I did not understand the preparation that it requires” (1T90).

Teachers have experience in managing group discussions, but with a different purpose than engaging in SSI. In fact, discussion is common with topics or subjects that are not necessarily scientific. For instance, teachers have experience in using group discussion in a subject called “tutoring”. This is a subject that normally takes about one hour per week in which the responsible teacher for that group of students addresses general aspects of their learning and the functioning of the school, as well as any conflicts that might arise within students in the same class: “I generally do not use this technique, although I do use it in other moments such as tutoring, for instance, where issues are discussed in small groups and then as a class, providing arguments for and against the decision made” (1T11).

One of the main efforts that teachers devote attention to when managing group discussion is promoting student participation. Some teachers refer to the whole group of students, which does not engage in the SSI, or does not engage to the level that the teacher expects. In the words of one participant: “I tried to organise a group discussion in the classroom (…). They did not participate and I had to ask them individually to write down their position about the issue” (1T38); “When I have done it, it’s been with the whole class, and there have been students who have not participated” (1T64). There are several reasons, one of which is the dynamics between students. For instance, one teacher asks: “How do we get those students who have trouble speaking in public, or who are intimidated by strong positions from their peers, to reflect and to talk?” (1T59). Another teacher shares that “I ask myself (…) how to those students who usually don’t talk to start talking. We have more strategies to calm down those who get too wound up or talk without letting the others participate” (1T103); “[The problem I have encountered is to] have them all participate and avoid a situation where only some of them monopolise the conversation.” (1T79). One teacher thinks of ideas for her next lesson with SSI and says that “this would provide a more comfortable space for those students who usually talk less, so that they talk more” (1T103). In some cases, students who participate the most are the ones who already have more interest or better marks. For example: “What I have seen is that it’s always the same 5-6 high-achieving students who always participate, and the rest say nothing” (1T60).

The size of the group-class affects, according to teachers, the success of student engagement with the SSI through group discussion. Teachers say that “There are more benefits of group discussion in small groups than with the whole class, because it gives everybody a chance to
present their arguments and it is more probable that all the students will feel more comfortable expressing their opinion” (1T18); “Often in a small group ideas come up that do not appear in the bigger group (…)” (1T42); “I guess that for those students who are more shy or even emotionally blocked it is better to work in small groups” (1T103). “I can’t think of ideas to put this into practice with (…) so many students in class” (1T43); “Small groups with well-defined roles help all students to actively participate” (1T89).

Some teachers establish a connection between student participation in a smaller group and their task as moderators. For instance: “I could apply this more easily in a split class, where the number of students is lower and therefore I can provide more personalised attention” (1T45). “Like this, I could split the class in smaller groups and moderate the discussions so that they could participate more” (1T38); “With smaller groups, all are able to participate, and I can better control individual participation” (1T64).

Teachers associate the idea of failed or non-productive group discussion to one or more of the following causes: deviation from the topic, and chaos or disorganisation. They express the need to stay focused on the topic in sentences such as: “Students deviate from the central topic” (1T42); “The truth is that sometimes conversations did not focus around the desired topic” (1T48); another teacher represents this idea by using a metaphor: “Students go out on branches instead of clinging to the tree trunk” (1T45).

Teachers feel confident about their role in compensating for this problem: “I think that in these activities, even if they are self-directed, the role of the animator is essential to avoiding anecdotal discussion and gets deeper into the goals of the lesson” (1T19); “I consider as key the figure of the teacher as a moderator (…) to orientate the discussion when it is superficial, or bring it back on course when it deviates to topics that are not interesting” (1T63).

Some teachers report past experiences where “The discussion could seem chaotic” (1T48). Another teacher is more precise about the meaning of “chaos”: “When I pose a discussion (…) it ends up in chaos, where everybody wants to talk” (1T52). One teacher uses the idea of conflict: “Every time I have brought up any conflictual topic or issue in the classroom, the fear is that the discussion creates a bit of chaos or disorder that overshadows the purpose of the activity” (1T42). Teachers make a lot of effort to keep students rational. For example: “Little by little, opinions and complaints arose and I was listening, always transmitting calm. (…) During the discussion, we regulated who had the right to speak, in what tone, for how long and active listening” (1T103).
1.2.3. Assessment of student learning

As part of the question of how science teachers can teach SSI in secondary school, assessment has to be planned and included. The following subsections present the results for case 1 per the main dimensions of assessment that have been established.

1.2.3.1. What is assessed

Regarding knowledge, teachers focus on assessing scientific content. However, they do so as part of a broader strategy that includes assessing other components. For example: “Evaluate the debate in an objective way (...). The concepts [content knowledge] will have been assessed through the lesson” (1T6). For example, one teacher plans to “Evaluate learning of the content, but also of the structure of the argumentative text and teamwork” (1T9).

Some teachers in case 1 collect information about what students think they have learned about the SSI, as separate from what they have really learned. For some teachers, this is a general habit, which they apply or adapt for teaching SSI. For instance: “[I would ask for] a short summary of what they have learned. We normally do this, as a sort of classroom diary” (1T9). Some teachers mention self-assessment and co-assessment indistinctively: “I think the best would be to prepare self- or peer-evaluation forms for students” (1T37).

Regarding skills, teachers in case 1 are interested in assessing the discussion component of the SSI. Some of them adopt a more formal approach, where they assess student participation in the class activity. One teacher proposes “Three evaluation criteria: respect taking turns and the opinions of others, order the arguments that are presented and contribute your own ideas to the discussion” (1T6). Other teachers focus on arguments about the SSI. For example: “I would assess whether their arguments have a scientific basis, as opposed to beliefs or opinions, regardless of the results [of the debate]” (1T109).

1.2.3.2. Assessment strategies

Most teachers assume that they are in charge of collecting evidence of students’ skills. They provide answers such as “I would observe...” (1T109), “Observing their reflections...” (1T44), “I would use...” (1T95). Regarding techniques, teachers state that the ideal would be to use rubrics (1T9, 1T37).
An important point made regarding strategies to assess student learning was teachers’ need to collect assessment evidence for each student, seeing that learning SSI may involve interacting with their peers. For instance, in reference to the final phase of group discussion, one teacher states that “It would be important to collect their conclusions in written form in addition to expressing the conclusions as a group” (1T18). The most common way to do so is by asking students to participate in an activity explicitly devoted to assessment. In case 1, some examples are: “a final argued conclusion” (1T18) or “a written statement of argumentation about the SSI” (1T9). Other teachers insert activities as part of the SSI lesson: “I collected their summary of the discussion and a final written individual conclusion supported by arguments in order to assess the activity” (11T18). As expressed by another teacher: “collect what has been written throughout the activity” (1T42).

1.3. Results for dimension 3) Resistance to SSI-based instruction

As was determined in the interpretative framework, the main results for this group of teachers are presented in the following subsections, for the categories that constitute this dimension.

1.3.1. Resistance on students

1.3.1.1. Student participation

For teachers in case 1, it was revealed that this obstacle affects the development of the whole lesson. For example, one teacher found it difficult that “students engage in a teaching and learning dynamic that gives them a more active role” (1T31). Teachers think that students are not necessarily aware that they are required to participate as part of learning SSI. For this reason, they think it is necessary to invest time in the lesson to promote student participation. They do so in an implicit way, as opposed to “asking” students to become involved. For example, in her reflection about the experimentation with an Engage material, one teacher proposes starting the discussion with a previous activity in groups of 3 students, with the objective of “them realising that they need evidences to influence/convince their peers” (1T90).

A tendency was identified whereby teachers use role playing as a way to ensure student participation in the lesson: “I divided the class into 3 groups of 10 and assigned them roles:
“Sometimes we organise discussions in science class (...) We do a role play, in which the different stakeholders are represented: politicians, neighbours, businessmen, scientists, members of environmental organisations,… Students have to look for information about each group in order to choose the right type of energy, and present arguments for the discussion” (1T9).

1.3.1.2. Personal involvement in the SSI

In case 1, the need for students to get personally involved in the SSI generates a tension between the teacher’s intention to engage students and the need to facilitate their learning. It is likely that SSI trigger student emotions because the topic has consequences for their daily lives, or because it is right or wrong. From a teacher perspective, this conflicts with the attitude that is needed in a formal learning setting. As stated by one teacher: “When they [students] have evidence, they are vehement towards their peers in order to persuade them to think the same way. They need to use other argumentation techniques to express themselves in front of their peers” (1T90). According to these teachers, students need the ability to manage and use these emotions productively in a learning setting (1T38). This could be why some teachers choose not to teach SSI at all. For example, one teacher says that “I tend to avoid ethical discussions with my students. I don’t like it because when I have done it, most students have a very selfish view – my family and I are the most important, others don’t matter- (...) and they are not capable of presenting an objective opinion that leaves feelings aside” (1T48). Other teachers are open to teaching SSI but “Ask [students] to justify their opinions during the discussion” (1T16).

Some participants hold a more extreme position and establish a contradiction between personal student involvement in the SSI and learning about the scientific aspects of the SSI. As expressed by one teacher: “I think discussion in a science classroom can be very useful when students have enough existing knowledge, so that they can argue using scientific criteria, not opinions” (1T11). Similarly, teacher 1T109 only considers arguments based on scientific facts as valid: “as opposed to just expressing their opinion, it has to be scientifically grounded” (1T109).

Another tension that teachers experience is between the need for personal implication from students in the SSI and the difficulties that students have in changing their minds. Through the learning experience, students may update their knowledge or what they think about an SSI on the basis of scientific evidence, or arguments made by their peers. For example, one
student could start from a position against banning the sale of sugary drinks in school vending machines, and after learning about the relationship between high sugar consumption and certain illnesses such as obesity, change their mind. Teachers have a feeling, however, that students maintain one opinion throughout the lesson. In the words of one teacher: “The hardest part for students is thinking about [argument] rebuttal (…) because they perceive [changing their opinion] as weaknesses of reasoning” (1T9).

Teach er propose solutions to the problem of persistent opinions among students during SSI lessons. As an example, one teacher suggests: “Making a certain group always defend the pros and another one always the cons (regardless of what they really think) so that they learn to express both types of arguments” (T8). Teacher 1T103 proposes explicitly addressing this issue with students in a dedicated learning activity. In this activity “You talk to the group and nobody listens, so that they can see how you feel when this happens to you” (1T103). In reference to the previous step of preparing a discussion, one teacher says that “This way, the discussion is much more productive: they put themselves in the shoes of the opinion they have to defend, even if it’s not their own!” (1T16).

1.3.2. Resistance on content load

A unique characteristic of formal education and especially science subjects is the existence of a curriculum that innovative teachers perceive as crowded and not possible to cover in the time allocated. The conflicts that SSI encounter in relation to this, according to this group of teachers, are analysed in this category for case 1.

This problem was confirmed in the specific understanding of SSI-based instruction that is analysed in this research. More specifically, most teachers phrase this obstacle in terms of time. For example, in a reference to classroom discussions about SSI, one teacher says that: “The benefits are obvious (…). However, there are also many challenges (…). And the worst part is that, generally, these [challenges] do not have to do with students, but rather with how much time is available” (1T36). Another teacher is more specific: “I understand the goal of (SSI), but I don’t really see how to put it in practice with my students (…). The time allocated is not enough for students to develop content knowledge; it would be too superficial for this educational level (…). I can’t think of ideas for putting this into practice with (…) so much content to teach” (1T43). Another teacher says that “I think (this activity) takes too much time, especially in an educational level with so much content load” (1T54).
Some factors affect the pressure of content that teachers feel. One of them is the year of secondary school they are teaching. The higher the educational level, the stronger the pressure teachers feel to cover more content in a short period of time. As expressed by one teacher: “In bachillerato [university-exam preparation educational level], we are always flying through the content” (1T37). Another factor is the moment in the academic year. At the start of the semester, teachers are more free, whereas “at the end of the year, the curriculum is so vast that often there is no time to cover it all, and doing it in this way means that more time is invested to teach the same content” (1T64). One teacher makes a reference to the order of the lessons that he feels is imposed by the curriculum: “The problem is that organising this requires a lot of time and practice. This is a problem because the content of the curriculum imposes an order to our lessons” (1T17).

However, teachers don’t think it is impossible to deliver SSI-based instruction in spite of the dense curriculum. As expressed by one teacher: “Modifications [in the Engage materials] would be needed to achieve the goals” (1T43). Some teachers propose specific ways of overcoming this challenge. A common one is to make sure that the SSI is related to curricular content knowledge, which is usually taught before the lesson. As stated by one teacher: “I have used the group discussion in class before, but never about scientific topics. My mistake was to assume that it wasn’t possible because students would not know the content well enough to have a discussion, but I have discovered a good practice, which is to research prior to carrying out the discussion” (1T64). Another teacher establishes a direct relation between how much time SSI-based instruction requires and students' abilities to engage in SSI in class: “The only way to solve the problem of [a lack of] time is that the activity to be done with students should be group work, without any content to teach. Hence, a possible solution for this could be to create an optional or specific subject about ‘team work in science’. In one term, there would be enough time to understand the philosophy of group work, and practice its different modalities in different sessions and with different issues” (1T17).

Other teachers propose to teach only a few SSI throughout the year: “I don’t think applying this model in all lectures is most convenient, although when done rarely and more or less periodically it can be a very useful resource for a science class” (1T63).

1.3.3. Resistance on organisation, schedule, and timetable

Teachers in case 1 believe that they need more time to develop an Engage material in class than what is allocated for it. However, they are aware that time is limited and that using time
for teaching SSI means taking time from other activities. As a solution, teachers propose decisions they can make that affect only them and their students. For example, giving up classroom time to teach SSI, or taking advantage of “split class” time. As expressed by one teacher: “Once a week, two science teachers take half a group of students each. I would do the first part of the activity with the whole group and in the split class, research information and discuss the SSI. I think I would summarise the conclusions again with the whole group” (1T9). The most common, though, is to use “homework” time. For example: “ask students to prepare their arguments at home” (1T38); “I think students could do part of the lesson at home…” (1T54).

Another position is represented by teachers who are willing to take action involving other people within the school. As one teacher says: “I would need to use the hours we devote to laboratory practice for this, but the science department needs to decide whether we should use the time for group discussion instead of laboratory practice” (1T38).

### 1.3.4. Resistance on teachers’ choice of SSI

It is known that teachers take their students’ knowledge, beliefs or interests into account when choosing an SSI to teach. In case 1, teachers mostly choose an SSI according to student interests. For instance: “Within biology, one of the discussion topics that is more interesting to students is …” (1T36). Some teachers use the word “curiosity”, in what seems to be an assumption of student interest: “I will use this resource with 3rd grade; it fits well with the content I’m teaching. I think it is a good resource, especially because the issue is very interesting and the key question will make my students curious enough to complete the work” (1T52). Another teacher mentions that “SSI promote curiosity towards learning, and student engagement in class” (1T44).

Other teachers look for SSI that are close to students, or that affect them: “choosing a good dilemma, a good controversy that affects them directly” (1T11). For example, one teacher comments on the Ban the Beds material that “Since [students] are so concerned with their physical appearance, I think it will hook them immediately” (1T79). Similarly, one teacher says that “I will choose the Big Bag Ban material because it is a topic that concerns them as consumers” (1T17). One teacher reports successful usage of group discussion to get students to talk and participate in class:
“Last Friday, I carried out a group discussion in class (...). To my surprise, it went way better than I expected (...). I took advantage of a problem with improper usage of mobile phones in class, because it has created a lot of conflict and controversy between teachers and students in the school. It has even caused a teacher to take a sabbatical without a salary (...). I told them I wanted to do a group discussion about mobile phones because it was interesting, even if it was not exactly related to the curricular content, but I would not do it if the topic was too sensitive for them. Without realising it, this was the perfect hook” (1T103).

It turns out that teachers look for SSI from sources related to how students spend their free time, such as television. One teacher proposes a lesson about the SSI of bringing extinct species back to life, and justifies it because: “Last week (…) Jurassic Park was on TV” (1T48). When reflecting on the activity, one teacher states that “Those 45 minutes were very useful for me, because I could see how students think, how they feel” (1T103). News coverage is also a common reason to choose an SSI. One teacher mentions that “We must focus on something more specific, taking advantage of an issue from the news, such as Ebola or Type A flu” (1T37). The vaccination issue came up because “A few months ago, in Olot [a town in the region where this teacher works], news broke out about an unvaccinated child who died of diphtheria” (1T54). As one teacher comments: “It would be helpful if the topic affects them, or is real or in the news” (1T109).
2. Results for case 2

This section presents the results of case 2 of this research. This is a different group of teachers than case 1. The data provided by teachers in this case was collected following the procedures determined in Chapter 3: Method and it was analysed using the same categories that were deployed in case 1. The most remarkable results are presented in the subsections below, as per the three dimensions that were set out for this investigation.

2.1. Results for dimension 1) Objectives of SSI-based instruction

In the same way as in case 1, in case 2 the affordances of SSI to reach certain objectives of science education were analysed. A short summary of each category in this dimension, as well as the main results obtained for each category, are presented in the following subsections.

2.1.1. Contribute to the development of scientific literacy

The data collection sources used for the 7 teachers in case 2 made it possible to identify the relations that they establish between SSI-based instruction and some objectives of science education, such as contributing to developing scientific literacy. According to the interpretative framework, the possibilities of SSI-based instruction to developing the three scientific competences have been evaluated, namely: 1) Explaining phenomena scientifically, 2) Gathering and analysing scientific data, and 3) Designing and evaluating scientific inquiry. The results of each competence are presented as follows.

2.1.1.1. Explaining phenomena scientifically

The competence of explaining phenomena scientifically describes the ability to use scientific knowledge and procedures to provide explanations about the natural world (Organisation for Economic Co-operation and Development, 2019). Teacher adaptations and usage of these materials made it possible to identify the relations they establish between SSI and this competence.

The materials that place a stronger emphasis on this competence are “Ban Cola” and “E-cigarettes”. Both sets of materials use scientific knowledge to explain phenomena: the
relation between sugary drinks and diabetes, and the impact of nicotine molecules on the human respiratory system. The teachers who choose to use these materials model the competence to explain phenomena scientifically. As stated by one teacher, his personal objective with this lesson is to “apply science to socially relevant questions”, as expressed in “Apply the particles model to analyse what happens in [students’] surroundings” (2T3). In the words of teacher T6: “This is the application of curricular content to solve a problem from our daily life”.

Using a different Engage material, teacher 2T4 is very conscious about human waste management and in particular the damage that non-biodegradable materials such as plastic can have on the environment. For her, the SSI about plastic bags works perfectly to help students explain the phenomenon of environmental pollution on the basis of the scientific knowledge gained about how bags disintegrate in the environment. For teacher 2T1, “Enceladus” material is a way to “Make them value the usefulness of science in their lives” (2T1). Another teacher, in reference to the “E-cigarettes” material, comments that this material is useful “Because the student must develop the aforementioned competences to become a citizen who appreciates the importance of scientific knowledge in the lives of people” (2T6) or “Because students need to see that the content of the official curriculum makes sense when it is applied in people’s lives” (2T6). Teacher 2T7 noted the “usefulness” of scientific knowledge to understand phenomena because “I want my students to start ‘loving’ science in a different way” (2T7). As stated by the same teacher: “I believe that (...) they must have a scientific base of topics that they do not consider as scientific or that otherwise would not have considered as scientific” (2T7).

Following the interpretative framework, teacher ideas have been collected about the issues that are considered relevant at the time of carrying out this research. Information about a) Health and Disease can be extracted from teachers who implemented the material “E-cigarettes” and “Ban Cola”. The teachers who use the E-cigarettes material argue how necessary it is to address this topic with students. In the words of teacher 2T7: “Some of my students smoke”, “Some of their parents use e-cigarettes” and “Most of my students think that these cigarettes are not harmful, which is a misconception”.

The “Car Wars” material is an example of scientific facts and principles related to b) Natural resources, to the extent that it deals with alternatives to fossil fuels. Teacher T6 chooses to use this material. From his responses to the lesson preparation and reflection forms, it can be inferred that students need to develop awareness and understanding of this as part of
their scientific and integral education: “Get to know different sources of energy, in other words fossil fuels other than oil” (2T4). Topic c) Environmental quality is represented in the “Big Bag Ban” material. Teacher 2T4 chooses this material because she wants students to “become aware of the environmental impact of using plastic bags” (2T2). Finally, there is a set of materials that is directly related to d) Frontiers between science and technology, which is “Life on Enceladus”. This material deals with space exploration, in particular the possibility that life could develop on one of the moons of Saturn, called Enceladus. This teacher justifies teaching it as part of students’ overall “general knowledge about the universe, which is fundamental” (2T1).

2.1.1.2. Evaluating and designing scientific enquiry

The usefulness of SSI in developing the competence known as evaluating and designing scientific enquiry was analysed for case 2. Regarding the material “Is there life on Enceladus?”, teacher 2T1 reports that it is useful for students to “develop an awareness of the need to research and investigate in space” (2T1). Another teacher says that her goals for the lesson about the SSI “Ban Cola” were “to apply the scientific method in scientific studies” (2T2). To that goal, she needs her students to “have a basic idea of the scientific method” in order to be able to approach the SSI (2T2).

More specifically, these two materials have to do with the results of scientific inquiry, where students have to determine to what extent there is sufficient evidence to make an affirmation, such as “if there is hot liquid water on Enceladus, it could be home to alien life” or “high sugar consumption may cause illnesses such as diabetes”. The teachers who implement these materials work thoroughly with students to help them critically analyse the aspects that are characteristic and key in scientific enquiry.

2.1.1.3. Interpreting data and evidence scientifically

Teacher responses to the data collection sources made it possible to identify trends in the contributions that teaching SSI make to helping students develop the scientific competence “Interpreting data and evidence scientifically”. The materials that address this competence more directly are “Big Bag Ban” and “Car Wars”. These materials deal with the process of collecting scientific evidence about how a certain system works. In the case of “Big Bag Ban”, evidence is collected about the properties of different materials, and in the case of “Car Wars”, about how an engine powered with renewable energy works. With this evidence,
students must answer a question. In the case of plastic bags, they have to determine which material is best, and in the case of Car Wars they have to determine which energy source is better. Teachers who use these materials show their understanding of this competence in the way they plan, develop and reflect on the lesson. In particular, for both issues it is very important that students can argue on the basis of scientific evidence, and that they arrive at a conclusion that is based on the data collected, as opposed to their preconceptions.

Teacher 2T2, who chose to use the material “Ban Cola”, establishes a link between this SSI and the need to help students navigate a world where they are exposed to a lot of scientific-looking information, which is not always scientific. In her own words: “Nowadays, seeing how easy it is for students to access information through the internet, it is very important that they develop basic criteria that helps them to sift through all that information, and know how to recognise which information sources are reliable and why”. Teacher 2T6, who also chose this material, says that she wants students to learn “to be critical about the information they receive, but in a reasoned manner and grounding their opinions in solid evidence”.

2.1.2. Teaching scientific knowledge

The previous section highlighted the contributions that teachers believe SSI can make to help students develop scientific literacy. This subsection deals with the contributions of SSI to the objective of teaching scientific knowledge. As explained in the conceptual framework, scientific knowledge is one way to represent the science curriculum. In the same way as in case 1, the data obtained through the data collection sources provided information about case 2. In this case, teacher descriptions of lessons with the Engage materials have been analysed according to the three types of scientific knowledge.

2.1.2.1. Content knowledge

Through their lessons, teachers in case 2 establish relations between the SSI that is proposed in the material and content knowledge. This can be seen in the lesson preparation and reflection forms.

The relations that teachers establish between SSI and content knowledge are generally consistent, adequate to the SSI, and specified with sufficient level of detail. For example, the teacher who chose to use the material “Is there life on Enceladus?” aimed to teach students about “the characteristics of a planet in order for it to be liveable (…), knowledge about the evolution of stars, and about the genesis and development of planets” (2T1). Further, he
argues for the relevance of teaching these scientific facts and principles to students because “Basic science knowledge is good for everybody”. The material “E-cigarettes” examines the scientific effects of inhaling nicotine from these devices by using the principles of chemistry and in particular the molecules model. Two teachers in this group (2T3 and 2T7) chose to use this material. Teacher 2T3 wants students to learn scientific content, i.e. “Behaviour of particles”. Therefore, in order to develop this activity successfully, his students must have precise knowledge about “the particles model”.

Teachers provide pertinent and relevant content knowledge that students need to have in order to learn about the SSI: “They have misconceptions about the origin of life and how life develops” (2T1). According to teacher 2T5, who implements the material “Car Wars”, which deals with fossil fuels, his students should know scientific facts such as “The different types of alternative energy sources to oil (hydrogen, biodiesel and electric)”.

For teachers in case 2, SSI are opportunities to teach content knowledge as part of a bigger problem that will not be solved or addressed in one lesson, but that may motivate students to learn seeing that it is part of something they can relate to. Teacher 2T5 is an example. He teaches a lesson with the material “Car Wars”, which deals with the scientific content of alternative energy sources to fossil fuels. He extends this content knowledge to other scientific facts and principles as part of a larger scientific issue, namely energy consumption on a global environmental scale. This is shown when in the lesson preparation form he includes among the objectives of the lesson “that students become aware of the ecological problems of excessive use of energy and that they see the importance of looking for renewable energy sources and with less of an environmental impact”. Teacher 2T4 does something similar. The material “Big Bag Ban” deals with content knowledge about the chemical composition of plastic polymers: their properties, how they degrade, etc. On this basis, the teacher uses this opportunity to teach students about a bigger problem, which is environmental pollution.

Other teachers who further develop the content knowledge that is proposed in the material provide scientific facts and principles that are not necessarily covered in the science curriculum. For instance, teacher 2T7 wants students to “Learn about different kinds of illnesses” while using material about electronic cigarettes which deals with content knowledge on respiration. The material “Big bag ban” deals with content in the area of chemistry regarding polymers, a type of plastic used for plastic bags because of its suitability for use based on properties such as strength, flexibility, etc. Teacher 2T4 implements this
material. By looking at the learning goals that she establishes for the lesson, she aims to teach her students about “The nature of different types of plastics that are used in the production of bags”, which is not a curricular element in her region.

2.1.2.2. Procedural knowledge

Compared to content knowledge, procedural knowledge describes science as a process. These are the processes involved in developing scientific knowledge such as analysing data, identifying patterns, etc. (Organisation for Economic Co-operation and Development, 2019). The Engage materials include learning goals that are related to procedural scientific knowledge. For this reason, teacher usage of these materials in their lessons reveals their approach to some of these processes.

First, teachers refer to the reliability of scientific knowledge. A key aspect of scientific activity as a process is that it is a socially accepted way to develop knowledge about the natural, physical world. The material “Ban Cola” in particular emphasises this aspect, as one of its objectives is “using evidence to decide whether a correlation is causal”. This deals with the scientific process of drawing conclusions from data. Two teachers implement this material. As a way to ensure that the knowledge developed is more reliable, teacher 2T2 talks about “applying the scientific method in scientific studies and makes it clear that “Not all studies have the same credibility”. For her, this knowledge should be developed in a society where there is a lot of scientific information available, which citizens consume, and should therefore consume responsibly. She claims that “we must know how to (…) read all the information in a scientific article or news report and not stick to just the heading. Teacher 2T6 wants “Students to learn how to be critical”.

Another assertion about the scientific procedures is about uncertainty, as in the lack of black and white affirmations. The case of teacher 2T2 is especially clear. As she puts it, “I want to show that it is difficult to be 100% sure of anything, and for this reason, we must know how to interpret results and data”.

Last, teachers point out that arguing for a position or phenomenon on the basis of scientific evidence is part of the scientific process. Some examples of this can be observed in this case. In the material about plastic bags, teacher 2T4 plans to “use scientific knowledge to reason about a proposal”, and to “defend an approach” in reference to the three different kinds of materials that plastic bags can be made of. Similarly, in the case of Car Wars, teacher 2T5
refers to “knowing how to defend the advantages and disadvantages” of each of the solutions proposed as alternatives to fossil fuels. In reference to electronic cigarettes, teacher 2T7 wants to ensure that “at the end of the lesson, they have their own ideas about a scientific topic”, which involves “contrasting their opinions”. In the case of teacher 2T2, the context-based learning experience through SSI is oriented not only toward teaching scientific content but a scientific skill. Teacher 2T5 mentions other learning goals related to scientific skills, including argumentation: “Knowing how to argue the advantages and disadvantages of each source of energy”. Teacher 2T6 clearly wants to help her students develop a scientific skill, which is “To express opinions in a reasoned way and based on solid scientific evidence” because, “students normally express not very scientific judgements which are only based on personal experiences”. The most often mentioned skill is checking the evidence supporting a scientific-looking statement, etc. One example from teacher 2T7 is: “By the end of the lesson, I want them to learn how to contrast their opinions (...) and discuss scientific topics”. Teacher 2T3 wants students to “Assess the risks and benefits of e-cigarettes”.

2.1.2.3. Epistemic knowledge

As stated at the beginning of this section, analysing SSI from the point of view of scientific knowledge involves characterising it from a content, procedural, and epistemic point of view. Epistemic knowledge is related to the purposes of scientific activity, which in the case of SSI involve the pursuit of science with and for society (see Chapter 2: Theoretical Framework). A few assertions can be made about the epistemic dimension of scientific knowledge, according to the analysis of teachers in this case.

Teachers stress the practical and solution-oriented approach to scientific activity. This approach describes the need perceived by teachers for scientific activity to address practical problems, as opposed to what is known as basic science or pure research. There has been much discussion within the epistemology of science of the extent to which science and research should focus on phenomena that do not directly pose a problem, versus a more applied view of research that starts from more specific and concrete problems. In these two opposing views, teachers in this case demonstrate a position in favour of applied science. In reference to the material “Ban Cola”, one teacher says that “[I] want my students to learn that] science helps us to look for answers or solutions to different problems, such as those that can affect our health” (2T2). Teacher 2T3 demonstrates a similar attitude when he comments that one of his objectives with this material is to “Apply science to issues of social relevance”. For teacher 2T4, it is also clear that scientific activity oriented toward developing
new, bio-degradable materials as an alternative to plastic bags can significantly improve the problem of environmental pollution. The same applies to teacher 2T5, who conveys to students that the alternatives to fossil fuels are a result of technological and scientific development.

The scientific process is seen as a reliable way to develop knowledge. From the planning and reflection of these teachers with respect to Engage material, their confidence in the scientific method as an approach to knowledge development and understanding the world is clear. Some teachers make this point by contraposing the scientific method and other, alternative systems. Teacher 2T1, for instance, comments that “students must be capable of talking objectively about the concept and definition of life on other planets, ignoring explanations and concepts rooted in pseudoscience”. He also states that “Many [students] continue to assign a mythological or religious origin to many natural phenomena or phenomena in general that they don’t know the explanation for”. Other teachers express their confidence in the scientific method without this opposition. For example, teacher 2T2 implicitly recognises the value of the scientific method to create knowledge when she says that she wants to “Show students how the scientific method is used to provide an answer to questions from our surroundings”.

Last, there is an association between science and the concept of progress. This sub-category describes a vision of science as a worthwhile activity to pursue as a society, in what seems to be an association between this activity and progress, wealth or worth. The material “Life in Enceladus” addresses this question, as it is set in the context of space exploration that is very costly. Teacher 2T1 chooses to use the material, and his position is clear: one of the objectives of this lesson is to ensure that “Students appreciate the importance of scientific development for the progress of society”. After the lesson, he recalls that one of his goals was to “Be aware of the need to research and invest in exploration of outer space” (2T1).

2.1.3. Convey the interdisciplinarity of knowledge

This category refers to the interaction across secondary school subjects, or disciplines. Teachers in case 2 agree on the relation between SSI and the integration of science or STEM disciplines. As expressed by one teacher: “Make them see the need to address any problem from a multi-disciplinary approach: biology, physics, mathematics…” (2T1). “They need to learn that the subjects we teach at school are interrelated” (2T1). Teacher 2T5, who uses the
“Car Wars” material, does so as part of an international, broader project that lasts longer than the lesson about types of energy, which is transversal to STEM.

Transversal skills or competences such as critical thinking are also present in case 2, thus showing the affordances of SSI to establish connections between experimental sciences and humanities, or knowledge from other disciplines, especially critical thinking: Teacher 2T6 talks about “Developing students’ critical thinking by analysing all the variables that intervene in finding the solution to a problem”. Some of these teachers relate this aspect to a critical way of being in the world, for example: “Developing a critical yet constructive way of thinking can help [students] in their daily lives” (2T1); “[Applying a theoretical model to a practical situation] is key to basic scientific competence that any citizen must have in order to be critical of the environment around them” (2T3). “Help my students to develop their own opinions” (2T5). Teacher 2T7 aims to “Help students to have their own ideas about a scientific topic” and “Compare and contrast their opinions”.

For some teachers in case 2, student development of the ability to explain natural phenomena scientifically is justified or enables decision-making. For example, teacher 2T3 focuses his lesson about “E-cigarettes” on the impact that nicotine can have on students’ bodies, in what seems to be an overarching goal of raising student awareness of these facts and promoting decision-making informed by this knowledge. Teacher 2T7, who uses the same material, wants to teach students to “Identify the risks of unhealthy habits” and “Avoid pulmonary diseases”. He plans to help them reach this conclusion by acquiring scientific knowledge about the effects of smoking in the human body.

### 2.2. Results for dimension 2) Components of SSI-based instruction

In this section, the results obtained in case 2 for the dimension 2) Components of SSI-based instruction are reported. As explained in case 1, the pedagogical dimension of this research evaluates how to teach SSI in science education, this is, the means to facilitate student learning of SSI. This dimension has been divided into: methodological approaches, techniques for discussing SSI and assessment of student learning. The following subsections provide a short summary of each component, as well as the main results obtained as a result of the data analysis of the group of teachers constituting case 2 of this research.


2.2.1. Methodological approaches: Inquiry-Based Learning

As with case 1, teaching SSI was analysed from the point of view of Inquiry-Based Learning (IBL). The evidence-based learning nature of the IBL methodological approach was assessed, seeing that that Engage materials propose situations where students learn about the SSI by collecting information from different sources, which can include experts, statistics, arguments from peers and others. Most teachers in this case carry out the SSI lesson following the steps that are provided in the material. They start and end the lesson with the teacher lecturing, while the students develop most of the tasks in between. This is a sign that teachers are following the evidence-based knowledge development model proposed in the lesson, where the learning goals are presented at the start, then students interact with the learning materials, and at the end a link is made with the objective of the lesson. By looking at the lesson preparation and reflection forms, it can also be seen that student-centred learning is a modality that takes more time in these teachers’ lessons with the SSI materials. Most often, the students work with teacher assistance.

Regarding the Inquiry phase, teacher adaptations in this group were elicited. In terms of phase 1) Engage, teacher 2T4 adds a video at the start of the lesson with the material “Big Bag Ban”. The video introduces the content of the lesson, because it is related to plastics. About phase 2) Extend, teacher 2T2 says that she would use the material again but next time she will add activities to keep students interested: “Maybe adding a video to the second part to keep them engaged” or “Adding an experiment, which they very much enjoy doing”, “to find out how much sugar Coca-Cola has”. Regarding phase 3) Evaluate, Teacher 2T5 thinks that there was not enough time for students to assimilate what they had done. Some teachers, for example, teacher 2T3 and 2T6, use this phase as a chance to wrap up. Teacher 2T6 in particular gives instructions for an activity belonging to phase 3) Evaluate to do at home, after the lesson.

2.2.2. Techniques for discussing SSI

2.2.1.1. Dilemmas

Through this group of responses from teachers on lesson preparation and reflection forms, as well as observation of their lessons, their way of presenting the dilemma was elicited.
The materials that place more emphasis on choosing between different alternatives are “Big Bag Ban” and “Car Wars”. The “Big Bag Ban” material engages students with the SSI of plastic pollution through a dilemma about different alternatives to shopping bags. Similarly, the “Car Wars” material teaches about the shift from fossil to renewable energies, posing the dilemma of “Which car would you buy?” with a choice of three renewable energy-powered car types.

The teachers who implemented these materials in class emphasised making a decision based on considering scientific evidence, as opposed to other reasons. Teacher 2T4 considers the different types of bags but leaves aside other aspects that play a role in this SSI such as the economic costs of producing alternatives to plastic. Teacher 2T5, who uses this material, is very good at helping students consider the pros and cons of each type of car, as a way to engage with the SSI of renewable energies, but leaves aside the more social aspects of the dilemma.

For both teachers, the dilemma was useful for engaging students with the SSI, to get them involved: “They all agreed that by paying for plastic bags, people would use them more responsibly” (2T4); “One of them thought that [bags] should be even more expensive, and others proposed alternatives such as cloth bags, baskets, or shopping trolleys” (2T4). Similarly, teacher 2T5 reports that he ensured that “students got to know the advantages and disadvantages of different energy sources”.

The main misconception that teachers demonstrated about the dilemmas used in case 2 is the lack of emphasis on the fact that the alternatives that are proposed in a dilemma are non-desirable. Generally, teachers tend to present one of the alternatives as more “preferred” than the other. For instance, the teacher who chose to implement the “Big Bag Ban” material is clearly positioned in favour of reducing or eliminating the usage of plastic bags as a way to reduce the problem of environmental pollution. Despite the materials or her intention to “assess the advantages and disadvantages” (2T4) of each material to produce plastic bags, her personal positioning is evident in the way she carries out the lesson and her responses to the lesson reflection form.

2.2.1.2. Group discussion

In a similar way as in case 1, discussion was analysed as a way to teach SSI, according to teachers from case 2. In the lesson reflection form, teachers were asked explicitly about how
the activities proposed match the characteristics of group classes, the classroom atmosphere, etc. as well as indicators of success with the lesson. This made it possible to identify trends in their attitudes regarding group discussion.

2.2.1.2.1. Students’ use of knowledge about the SSI in group discussion

Evidence was provided by teachers in case 2 about group discussion as a useful way for students to express knowledge about the SSI. For instance, the objective of teacher 2T6 is for students to analyse the variables that play a role in an SSI through discussion.

The observation forms demonstrate that teachers use group discussion as a way for students to use, apply and test certain facts about the SSI. To achieve that goal, they may use their own knowledge, but teachers mostly have them use arguments and information that they have been provided, such as results of scientific research, expert opinions, etc. Teachers appreciate this aspect of group discussion, even if they recognise that their students are not used to it. For example, when asked about the difficulties that the lesson might present to students, teacher 2T4 mentions “the difficulties of defending a point of view”, which she relates to students’ “lack of practice”. This is confirmed after the lesson: “the most critical moment was when students had to argue for an opinion, because they were afraid of making a mistake”.

2.2.1.2.2. Rules of group discussion

Teachers in case 2 invest some time in preparing the discussion, mostly reminding students about the rules. Students are grouped according to how they are sitting, in groups of four.

2.2.1.2.3. Managing group discussion

The problem of “quiet students” is associated in case 2 with the dynamics of a group class that may constrain individual students from expressing their opinions. Teacher 2T6 is aware of this. This is shown in her response to how to gather evidence that the students achieved the learning goals: “I asked students to make a personal reflection in which I could assess each opinion in an individual manner regardless of the peer pressure of the larger group” (2T6).

Even when students do engage in the discussion, this group of teachers talks about the challenge of moving the discussion forward smoothly. This process has two moments: first, stating an opinion; and second, listening to others. Teacher 2T5 makes a reference to the
first part: “Open questions, such as how much carbon dioxide cars release, always create havoc that is not recommended. For this reason, I tend to avoid them”. It is clear from the words of this teacher that chaos is not a good thing. Even teacher 2T3, who claims to work with a group of students who are very used to discussion activities in science class, states that “everything worked, but students intervened a lot, so we kept changing from one topic to the other”. This suggests that for this teacher the activity was a slightly superficial because students incorporated new points of view, thus contradicting the idea of a more organised, productive and step-by-step lesson.

The idea of order, rationality and a generally calm discussion is used by other teachers to express the same concern. Teacher 2T2 claims that the lesson will be successful if: “students discuss, agree and express their opinions while respecting each other”. In the case of teacher 2T6, when reflecting about what she considers a successful lesson using the Engage material, she states that “The dialogue that was established between the students from each group, as well as the respect that they showed toward other people’s opinions, was a success”.

Some evidence was found in this case supporting the role of the teacher as a facilitator of group discussion about an SSI. For instance, teacher 2T3 believes that part of the success of the lesson depended on him: he is satisfied with “how [he] let students talk” and “how [he] asked them direct questions”.

The size of the class is a factor that influences discussion of an SSI. Teacher 2T6 shows awareness of this problem. She chooses to organise the discussion “in groups, which will help them learn to respect the opinions of others and reach consensus” (2T6). Teacher 2T2 chose a group of students which is “very open” and “half the size of the normal class” to try the Engage material.

### 2.2.3. Assessment of student learning

As stated in case 1, part of how secondary school science teachers teach SSI involves assessing student learning. This element is developed from the point of view of what is assessed, and techniques for assessment.

#### 2.2.3.1. What is assessed

The data shows that teachers in case 2 have no difficulties in assessing student knowledge as proposed in the materials. Content knowledge is very prevalent in their SSI lesson assessment.
plans. For example, one teacher states that the lesson will be successful “If students learn the differences between the main alternatives to oil” (scientific content of the SSI). For teacher 2T7, the lesson would be successful “If the learning goals are met”, where the learning goals include drawing diagrams of particles (scientific content of the SSI).

Regarding skills, teachers in this case focus assessment on the discussion aspects of the SSI. For instance, teacher 2T5 says he will be satisfied if students “Show the ability to determine the pros and cons”. Teacher 2T7, who implements the material about electronic cigarettes, wants to assess the skill of weighing risks and benefits. Teachers do not seem to have difficulties with assessing student awareness that the scientific claims supporting an SSI are under discussion. This is the case of the “Ban Cola” material, where a teacher says that she wants to assess “The skill of critically assessing the scientific information they read” (2T2).

Some teachers in case 2 also assess student participation in the learning experience. The assessment indicators of teacher 2T2, for instance, are whether students “Enjoy the activity”, and “Discuss”.

### 2.2.3.2. Assessment strategies

The general feeling is that teachers are in charge of performing assessment. No evidence was found that students assess their own learning, even when the material included a checklist for students to document their decision about the SSI.

How teachers collect individual data from students was also analysed in case 2. Some teachers ask students to deliver an assignment. For example, teacher 2T6 structured the lesson in a way that students worked in groups, but she also wanted to know to what extent each student had acquired the knowledge about the SSI. For this reason, she asked students “To write a personal reflection on the activity, in which they are not influenced by peer pressure”. Other teachers use classroom time to check students’ individual learning. As stated by one teacher: “I could see that the majority of students reached the objectives, seeing the questions I asked at the end” (2T7).

Other teachers focus on collecting evidences of the activities that students do throughout the SSI lesson. For example, one teacher collects student learning evidences “By looking at the results of the student sheets” (2T3). He “Looked at the drawings” to check understanding of content and “listened to the discussions” for the skills (2T3). Another teacher claims that
“Seeing how students participated in the lesson, I could see that they reached the learning objectives” (2T2).

2.3. Results for dimension 3) Resistance to SSI-based instruction

Analysing the resistance to SSI-based instruction in science education was performed for case 2 as for case 1.

2.3.1. Resistance on students

2.3.1.1. Student participation

Most teachers in this case are aware that student participation is key for the success of SSI teaching. This is primarily seen in the group of students with which teachers chose to try the material: teacher 2T3 applied the Engage material with “a very active group of students” who “are used to being asked for their opinion in my class”. According to teacher 2T7: “[Students] are not used to this sort of lesson” but he seems optimistic because “This group is very motivated about this subject and with scientific dilemmas”. Other teachers express this awareness as challenges to the Engage material that they want to implement: “My students are not used to doing these types of activities, involving discussing in groups and expressing their ideas” because “Normally, I guide the learning activities” (2T2). Two teachers in case 2 reach the same conclusion, but after the lesson. Teacher 2T1 states that “It was difficult for them to understand that they had to determine themselves which pieces of evidence were reliable”. Similarly, teacher 2T2 reports that it was challenging for her to keep students engaged during the whole lesson: “They were less motivated at the end” and “The second part of the lesson felt boring for them”.

Some teachers in this case include student participation as a goal for the SSI lesson. For instance, teacher 2T4 wants “To make all students participate in the lesson”. In this sense, she thinks that “The student sheets worked really well” and make students talk, whereas “I was not so comfortable with the slides”, which correspond to the parts of the lesson where she provided more unidirectional instruction.
Another teacher reports that “only a couple of students who participated very little in the activity did not reach the learning objectives” (2T7). It seems that for this teacher, there is a relation between student participation and learning about the SSI.

2.3.1.2. Personal involvement in the SSI

Analysis of the data collected in case 2 revealed that teachers invest effort in achieving personal involvement by students in the SSI, as expressed in different ways. One way is their justification of why they choose the SSI. For instance, teacher 2T1 says that “these types of topics may be of their interest, especially if they are ‘hot’ topics in the news”. They also invest effort during the lesson, by asking questions that are not necessarily posed in the material that they are using, such as “what do you think should be done about this?”, “Do you think sugary dinks should be banned? There are no right or wrong answers. I just want you to justify your opinions” (2T2).

Teachers mostly succeed in involving a number of students that they consider sufficient. They pay attention to students’ personal involvement in the SSI, also beyond the teaching and learning experience. Teacher 2T4 learns that “students thought they had to pay for plastic bags for monetary reasons, not for environmental reasons” and another teacher ends up discovering that “some of them had even tried [e-cigarettes]” (2T7). However, some teachers succeed better than others at using this personal involvement to their advantage, namely in teaching the SSI. The data in this case showed that this depends on the level of teacher experience with teaching SSI or similar topics, the relation they have with their students and their teaching style.

2.3.2. Resistance on content load

As stated in case 1, the need to cover a long curriculum within a limited time has been analysed as an obstacle to SSI teaching by secondary school science teachers for case 2. This conflict was confirmed in teachers’ experimentations with an Engage material. When teachers are asked to what extent they met the goals they set for the lesson, they reveal that in general, they were not capable of achieving them all. Teacher 2T4 explicitly states that “the objectives related to content were maybe not reached”.

Evidence about how teachers find a balance between SSI-based instruction as an educational innovation and the need to cover the “overcrowded” science curriculum was found in this case. Teachers were asked to determine the learning objectives for their lesson involving an
Engage material. It was found that teachers include different types of content, described as knowledge, skills and attitudes. The most common is to include knowledge and skills, as per teachers T1, T2, T3, T4, T5, and T7. For example, T1 includes “general knowledge about the evolution of stars and about planet creation and evolution”, as well as the skill of “being capable of talking in an objective way”. Teacher T5 sets a learning goal that includes knowledge and skills: “to know the different types of energy alternatives to gas (hydrogen, biodiesel and electric), knowing how to argue the advantages and disadvantages of each”.

Another technique found was to include several learning goals in the lesson. Some teachers in this case include the learning goals that are set out in the Engage material, but they add other, mostly content knowledge related learning goals. For instance, when asked about the objectives that he sets out for the lesson with the e-cigarette material, Teacher T7 refers to “the objectives that are stated in the Engage material”. Later, when asked about the learning goals that he wants his students to reach through the activity, he adds skills such as “contrasting their opinions” and “discussing a scientific topic”. Teacher T4 is another example. In the material “Big Bag Ban”, the learning goals are the following: in terms of knowledge “properties of polymers”, and in terms of skills “evaluate the merits of a solution to a real-world problem”. In addition to references to this content in her lesson planning, this teacher adds other learning objectives that make a direct reference to another aim, which is developing a commitment to preserving the environment. Teacher T2 also seems to be trying to take the advantage of using the “Ban Cola” material to address important curricular aspects in her subject. From her lesson preparation form, as well as the lesson observation form, this teacher covers the contents of the material and adds “the scientific method” as a way to develop knowledge about the world.

Another manifestation of how to cover a lot of content in a short time can be extracted from the adaptations that teachers make to the material in order to use it in a lesson. Teacher T7 explicitly points out that “the part about gas dispersion went a little bit beyond the curriculum, but we linked it to pollution, which is a curricular goal of this subject”.

2.3.3. Resistance on organisation, schedule, and timetable

How to deliver SSI-based instruction in the light of the usual time allocated for science lessons in secondary school was analysed in case 2. A common trend is that lessons are shorter than what is planned in the material. Teachers admit to not having had sufficient time to complete the Engage material in one lesson, or having had to change things “on the
go” in order to finish it. For instance, teacher 2T6 reports that “I would not change the materials; they are fantastic. I would just allocate more time for each of the activities in this material”. For some teachers, this gap is not too big. In the words of teacher 2T2: “I will adjust a little bit the timings indicated for each part, seeing that the classes in our school last 50 minutes, and considering the time needed to get started, I can count on 45 minutes at the most”. Other teaches, such as teacher 2T5 seem to need way more time, as he claims that “I would do it in two lessons”. Teacher 2T6 holds a similar position, while saying that “I would allocate more time for each of the activities in the material” (2T6).

Teachers associate the lack of time to different aspects of SSI-based instruction. For teacher 2T3 it is due to the discussion component: “We ran out of time, but it did not seem adequate to stop students talking about what they were curious” (2T3). Similarly, teacher 2T6 says that “one hour is too short if the goal is to carry out a participatory discussion, in which enough students participate”. One teacher states that “Using more than one type of [learning] activity in a single lesson is complicated because for each type of activity, students need to focus, and for that they need time” (2T5).

Another reason for going overtime is practical. Teacher 2T1 states that: “In spite of all the preparation work, I found out that all the files I had left in the computer had been removed. The internet was not working, and I had planned to show them a video (…)”. After the lesson, he adds that “most certainly, next time I will do it in two lessons, because seeing all the technical problems (which are nonetheless usual), it is clear [to me] that in order to be able to complete everything, using all the sources of evidence, I need more time than what we have in one lesson” . Teacher 2T6 holds a similar position. She points out that “I was lucky to carry out the activity in the lab, which means that I had everything ready for when students came in. If the teacher gets to the classroom and must prepare the projector, the computer, load the videos and the presentations, as well as arrange the tables to sit in small groups, a lot of time is wasted on these activities”.

Some teachers associate lack of time to both SSI-based instruction components, and technical. Teacher 2T1 would use the material again but “Split into two lessons, considering all the technical problems that I encountered and the time that it takes to consider all the evidence”.

Among teachers who prioritise finishing on time, the most common changes were to skip activities in the IBL sequence. For example, teacher 2T4 planned to show them a video but
in the end she didn’t because of time. Another technique is to stop students from talking. Teacher 2T5 says that “The time slot allocated for discussions is 5 minutes, which is not feasible”. To solve this problem, he says that “In order to have time for everything, instead of making students discuss their first reactions in small groups, we will do it as a whole group”.

2.3.4. Resistance on teachers’ choice of the SSI

The importance of choosing the right SSI was also assessed in case 2. First, it was wound that teachers only realise this after the lesson. A clear example is from teacher 2T1. One of his goals in using the material is to make students interested in learning. In this sense, the Engage material was suitable in theory, because is embeds the content in learning an issue that the teacher believes could be of interest to students. However, he reports that student participation was low, which did not really help him to achieve the objectives of the lesson. Teacher 2T5 has a similar experience.

It was found that a way to overcome teachers' choice of the SSI as a resistance to SSI-based instruction is to choose SSI that are appealing to students. For teacher 2T1, student participation is related to the SSI chosen. As a result, this teacher thinks he should choose an SSI that is more interesting to students to ensure their participation. The comments from teacher 2T5 reinforce that an essential point for the success of SSI-based instruction is a focus on “keeping students interested” rather than on the content of the lesson. In the open ended questionnaire after implementing an Engage material, this teacher reports that the lesson indeed engaged his students, but he was too focused on the learning goals and didn’t listen or take into account student input. He believes this is why students disengaged from the activity.
CHAPTER 5

DISCUSSION
Chapter 5: Discussion

The previous chapter presented the results for the two case studies that constitute this investigation. Following the designed methodology, the present section aims to add new knowledge to what is already known about how teachers deliver SSI-based instruction, as it was expressed in Chapter 1: Introduction and objectives. This process includes understanding the results in light of existing empirical knowledge, when comparable. To that goal, the present chapter provides a discussion of the results obtained, by dimension.
1. Dimension 1) Objectives of SSI teaching

This section discusses the results obtained in dimension 1 of this research. This dimension sees SSI as a means for science teachers to achieve the goals of science education in a science and technology-rulled society, which in this research are expressed in the following categories: a) contribute to the development of scientific literacy, b) teach scientific knowledge, and c) convey the interdisciplinarity of knowledge. The results obtained for each objective are discussed below.

1.1. Contribute to the development of scientific literacy

Following the PISA 2018 framework, scientific literacy is composed of the following competences: 1) Explaining phenomena scientifically, 2) Evaluating and designing scientific enquiry, and 3) Interpreting data and evidence scientifically (Organisation for Economic Co-operation and Development, 2019). The affordances of SSI as a means to help students develop each of these competences, according to teachers, are discussed below.

1.1.1. Explaining phenomena scientifically

The ability to explain phenomena scientifically requires using scientific knowledge and skills to understand phenomena taking place in the natural world. The main finding was the identification of three interpretations. One sees SSI as real-world problems, this is, phenomena that can be explained scientifically and are thus worth covering as part of science education. In other words, rising sea levels or GMOs, or how to develop a vaccine, etc. are phenomena that students need to know how to explain in a scientific way. This suggests that science teachers conceive SSI as part of the natural world, and that at least have some importance for them as well as other strictly scientific phenomena.

This is consistent with existing conceptualisations of SSI for students, which are more in line with current attitudes about how science should be taught – incorporating more than strictly scientific-based approaches – in secondary school. Therefore, it is remarkable that teachers share this understanding about SSI as a way to bring the science curriculum closer to new domains and places where science is present.

What these issues are has been discussed in the context of reflection on the goals of formal education within a science and technology-rulled society (Kolstø, 2001; Wan & Bi, 2020).
Thus, it is important for teachers to know what these issues are because they are gatekeepers between the “real world” and what students experience in class. To shine light about this question, this study analysed teacher interest in topics that are considered of special interest at the time of carrying out this research, according to PISA science contexts (Organisation for Economic Co-operation and Development, 2019), namely a) Health and disease, b) Natural resources, c) Environmental quality, and d) Frontiers between science and technology. Of those topics, teachers showed more interest in cases related to a) Health and disease and c) Environmental quality, followed by b) Natural resources and d) Frontiers between science and technology. These results confirm that teachers feel similarly to the rest of society regarding the issues that contribute to a higher level of discussion or controversy in society because of the impact they have on our lives, such as those related to health and environment (Kolsto, 2001).

Furthermore, it was found that these teachers are clearly positioned on these topics, and transmit this to their students in class, for example, the need to reduce the use of plastic, or issues that affect student health, such as smoking or dietary habits. This raises the question of how teachers’ own beliefs and understanding of the SSI influences how it is taught, as has been suggested in previous research (Kilinc et al., 2017).

Another interpretation sees SSI as a way to revitalise the contents, especially knowledge and skills, which are laid out in the science curriculum. Teachers acknowledge the gap in content knowledge that is taught at school, and the ability to explain phenomena scientifically that is needed nowadays. Some contents in the curriculum can be, according to teachers, too abstract and isolated, whereas interaction in modern society requires citizens to know content knowledge in context. The data shows a tendency for teachers to think it mostly makes sense to teach scientific facts and principles to the extent that they allow one to understand or solve real-life problems. Indeed, this research showed that teachers may think that applied science is more relevant to students, in contrast with basic or abstract science. This is in line with current changes in the curriculum that have incorporated, for instance, the subject of “sciences for the contemporary world”. Therefore, SSI could facilitate this change.

The third and last interpretation sees SSI as a vehicle to practise the ability to explain phenomena scientifically in class, strictly as a school activity. Teachers are aware that SSI are real-life problems, but they do not treat them as such in class. Instead, they consider them as a way for students to apply knowledge, skills, or attitudes to making a decision in what could be a “simulation” of real life. The focus for those teachers is not that students learn
the SSI itself, but to work with scientific knowledge and skills in an integrated manner. SSI are a way to keep learning this content and the skills that are meaningful and relevant to students, because SSI are very close to students’ daily lives. They are easy to recognise and understand for students because they are related to areas they deal with on a frequent basis, such as what they eat, the weather, products they consume, or news they may have heard of outside school. This suggests that considering that science teachers need to teach how to explain phenomena scientifically, SSI are a useful vehicle because they are examples of these phenomena, which hold added value to the extent that they may be more relevant or interesting to students than just scientific issues or topics. This finding is similar to previous studies showing that for teachers, SSI are helpful tools to make explicit for students that learning science curricular content is useful for daily life, because they show that scientific knowledge is present in real-world problems (Albe et al., 2014).

Another finding in this category is about how to explain SSI as phenomena from the natural world. Teachers think it is possible to explain the SSI proposed in the Engage materials with content knowledge, but they also agree that procedural knowledge can provide plausible explanations for these phenomena. For example, teachers explain how the SSI on tanning beds and skin cancer can be understood from a scientific angle in the discipline of physics, with knowledge about how tanning beds do not filter UVB rays. To achieve this understanding, students may also use procedural knowledge such as the procedures and forms by which this knowledge is obtained (analysing graphs, calculating percentages, etc.). Another example is the SSI about sugar drinks, which teachers agree that it is possible to approach in a scientific way, by using content knowledge about how the human body processes food, and procedural knowledge of cause and correlation to assess the relation between these drinks and illnesses such as diabetes. This understanding is consistent with the definition of this competence, which describes students’ ability to draw on different types of knowledge and skills in an integrated manner to understand each phenomenon. This study thus provides evidence of how teachers consider SSI a useful tool for teaching science content, as has been suggested in previous literature (Ekborg et al., 2013; Tidemand & Nielsen, 2017). At the same time, however, it provides evidence for the co-existence of content knowledge with other types of knowledge in SSI-based instruction.

Moreover, it was found that of the three scientific competences, explaining phenomena scientifically is most represented in teacher statements about the relation between SSI-based instruction and developing students’ scientific literacy. This result can be explained by
considering variables such as science teachers’ initial education. In Spain, a science teacher’s initial education consists of a Bachelors’ degree in a science discipline (biology, chemistry, physics…), lasting for four years, and a one-year Master’s degree providing specialised pedagogical training in that discipline. This model shows, first, a strong emphasis on their disciplinary education, compared to the pedagogical aspect. This disciplinary training reproduces the ability to explain phenomena scientifically because it provides an understanding of the natural world from that discipline through facts, rules and systems. Second, in their pedagogical training, teachers may have been exposed to students’ scientific competence as it was defined until a decade ago in the curriculum, which has been defined as ambiguous and emphasises “scientific competence for scientists” (Garrido & Simarro, 2014). Of the three scientific competences, explaining phenomena scientifically is the closest to this vision of scientific competence. The implications for supporting SSI-based instruction are that the growing importance of SSI may give rise to the need to rethink initial science teacher education curricula to help them develop the necessary competences.

1.1.2. Evaluating and designing scientific enquiry

The first finding regarding the relation between SSI and the scientific competence “Evaluating and designing scientific enquiry” is that teachers think SSI are useful for training students in a way of thinking that they consider their responsibility to teach, which is to ask scientific questions. According to teachers, not only SSI have the potential to be researched in a scientific way, but students may find it easy or appealing to do so, compared to other issues.

The second finding is the relations that teachers establish between SSI and the need to provide students with tools that help them assess the quality of scientific enquiry. For teachers, SSI may arise as a result of the publication of scientific studies, such as research about the relation between meat consumption and colon cancer (see Chapter 4: Results). When presented in this way, SSI offer the opportunity to teachers and students to work with a real-life scientific enquiry, thus making the learning experience more purposeful. For teachers, this is a good way to start building on this competence, rather than approaching it in an abstract way. More specifically, teachers believe that students have a tendency to believe or spread the results of scientific enquiry as they are communicated through media, without questioning it. To compensate for this tendency, teachers think that critical thinking is a very
important skill. Seeing that critical thinking is not traditionally part of science education, SSI seem like a good vehicle to practice this skill in science class.

1.1.3. Interpreting data and evidence scientifically

Regarding the affordances of SSI to teach the scientific competence of interpreting data and evidence scientifically, it was found that the type of data and evidence that can be interpreted scientifically is very diverse. The scientific, societal, political, and economic aspects of SSI appear in the media, which are discussed publicly in the context of open science and information society (Díaz-Moreno & Jiménez-Liso, 2012). Thus, for teachers, SSI extends the type of evidence and formats susceptible to be analysed scientifically, which may include actual data collected from natural phenomena, but also data that is under discussion or interpretation such as experts’ point of view, or the views of people who are affected by an SSI.

Another finding is that interpreting data and evidence scientifically involves updating one’s opinions or beliefs about the SSI on the basis of the evidence that is provided. In this process, teachers stress the need to assess to what extent the data and evidences are trustworthy. In fact, teachers tend to think that scientific information, especially about sensitive or controversial issues such as SSI, can be biased or non-reliable. SSI are useful to work on this aspect in science class.

Another process for which SSI was found to be useful is abstraction from data to knowledge. In particular, teachers’ understanding of SSI in this light is aligned with Socioscientific Reasoning or SSR (Troy D. Sadler et al., 2007), which is a set of competences that help students deal with SSI, based on the fact that scientific literacy or competences as they are defined are not representative of a SSI society. More specifically, the ability to see multiple perspectives is the SSR skill that is most represented in this study. These results may constitute evidence for the validation of this construct. If teachers are to help students develop this set of unique SSI competences, it is a good sign that teachers identify SSI with them. Secondly, it suggests the power of SSI to drive change in educational practice even if it is not supported by changes in the curriculum, just by their incorporation.
1.2. Teach scientific knowledge

Results were obtained about the potential of SSI teaching to teach the three types of scientific knowledge, namely, content, procedural, and epistemic, and are discussed as follows.

1.2.1. Content knowledge

Content knowledge is described as scientific facts and principles, as they are covered in the curriculum. The main finding in this sub-category is that there are relations between the SSI provided in this research, which covered different topics as per the PISA contexts (Organisation for Economic Co-operation and Development, 2019), and content knowledge as it is covered in the Spanish National or regional curricula. For example, teachers think that the issue about life in Enceladus (a moon of Saturn) is related to content knowledge about the solar system and planet formation, which is covered in different STEM subjects. Another example is the SSI about E-cigarettes, which teachers relate to content knowledge about molecules in the subject of chemistry. This finding suggests the diversity of curricular scientific facts and principles that can be taught by means of SSI. Furthermore, it confirms that teachers share theoretical conceptualisations of SSI as a way to teach content knowledge in context (as opposed to procedural or epistemic (Tidemand & Nielsen, 2017). Based on this conceptualisation, classroom materials and lesson plans are currently being developed. Therefore, it shows that these SSI materials meet teachers' needs.

More specifically, it was found that teachers establish relations between the SSI and well established scientific facts and principles from disciplines such as physics, biology, or chemistry. This suggests that when used to teach content knowledge, SSI teaching might occur within the boundaries of a discipline, which is usually taught by one teacher. This may conflict with efforts being made to make secondary school teaching more holistic, with initiatives such as competence-based learning, drawing teachers back to their discipline and the SSI that arise within it. However, from the point of view of change and innovation in science education, the close connection between SSI and the discipline enables SSI to be taught in practice.

This study also shows that teachers further develop the content knowledge that the SSI is related to. They see SSI as a way to enrich their lessons with more content in the form of scientific facts. For example, teaching about Genetically Modified Organisms (GMOs) as part of a bigger project about sustainable development or genetics. This provides some
evidence supporting the usefulness of SSI in teaching multiple types of content knowledge in a single lesson or project. Teachers see this as valuable for two main reasons. One is that it increases the efficiency of science teaching, the other is that establishing connections between the contents of a subject makes learning more meaningful to students.

Another finding is that teaching SSI helps to either teach content knowledge (scientific facts and principles), or to apply them to a new situation. For example, different teachers use the SSI “E-cigarettes” for teaching about the particles model, or to how to apply it. According to the curriculum, students must learn the content but should also be able to transfer it to new situations. In this light, teaching SSI seems like a flexible tool for teachers to achieve both goals, depending on their needs, the needs of the curriculum, and their students. Moreover, the data showed that teachers organise their teaching or yearly programme according to blocks of content, following the curriculum. In parallel, SSI take place in real-life and gather attention from the media at a time that is outside teachers’ control. The fact that teaching SSI is useful for teaching and applying content suggests that if an SSI becomes relevant at a certain point in time, the teacher may use it to teach the content if it has not been taught already, or to apply it, if it has. Moreover, the need for students not only to learn the content but to be able to transfer it to new situations is a relatively new incorporation in the science curriculum as determined in international assessment tests as well as national and regional curricula in Spain. In this light, SSI appear to be useful tools in achieving this goal.

1.2.2. Procedural knowledge

This sub-category describes “knowledge of the procedures that scientists use to establish scientific knowledge” (Organisation for Economic Co-operation and Development, 2019), p. 100. SSI have been presented as a useful way to teach procedural knowledge. As a result of this study, one finding was that teachers emphasise the usefulness of SSI in teaching about the mechanisms that science uses to reduce uncertainty, such as ensuring that the definition of concepts is clear and that the procedures used to collect and analyse data are rigorous.

Moreover, teachers establish relations between SSI and the fact that it is difficult to ensure that scientific facts or knowledge are 100% true. Instead, they are open to interpretation. Teachers talk about argumentation and justification of claims as very important processes of scientific activity. These are relatively recent incorporations in science curricula and international assessment tests, thus SSI seem like a useful vehicle to support them in formal science education. This is a good result because several authors have emphasised
argumentation as a key process for students to deal with SSI in science education (Evagorou et al., 2012; Namdar & Shen, 2016).

1.2.3. Epistemic knowledge

Finally, epistemic knowledge is defined as “an understanding of the role of specific constructs and defining features essential to the process of building scientific knowledge” (Organisation for Economic Co-operation and Development, 2019), p. 100. The main associations between SSI and epistemic knowledge that were found are: the scientific process as a way to apprehend the world, the type of scientific knowledge that is worth developing as a society, and the consequences of scientific activity.

With respect to the first association, teachers establish relations between SSI and the scientific process as a way that helps humans apprehend the world. According to teachers, the scientific method is consistent with current social values in terms of a rational, objective way to create reliable knowledge. This is, in their opinion, more necessary than ever in a moment where other types of methods are gaining attention despite the fact that their processes are not clear, such as pseudoscience, or other ways to develop knowledge based on faith, for example religion. They think that SSI are unknown phenomena that should not be understood using these methods, but through scientific enquiry. Therefore, SSI appear to be useful in promoting meta-reflection about the very act of scientific enquiry, both in students and teachers. It is of special interest that the existence of a single scientific method has been challenged by the assumption that there are several forms of scientific enquiry. This is reflected in educational theory (Vázquez-Alonso & Manassero-Mas, 2016), but also secondary school curricula and international assessment tests such as PISA (Organisation for Economic Co-operation and Development, 2019). This level of reflection was not represented in the data, thus it can be inferred that SSI as they are presented in this study do not promote reflection about epistemic knowledge at this level.

The second finding is about scientific advances and societal progress. Teachers express this idea in terms of cost. They question the need to invest public resources in scientific research that does not have a straightforward impact on society, such as for example, certain space exploration missions. Teachers believe in the need to develop scientific activities that solve or have a direct relation with people’s problems, that respond to the problems that society is facing, or address its needs, for example, in research priorities. It seems that teachers prefer, at least in the case of SSI, “applied research” rather than “pure research”. One implication
for using SSI to teach epistemic knowledge is that in science teaching at this level, basic science is not a priority, according to these teachers.

Finally, teachers highlight that scientific activity may entail non-desirable consequences for the people or scientists involved, such as accidents. The ownership of scientific knowledge or patents was also raised by some teachers as important. These views are consistent with early reflections about the relation between science and society, and especially with “consequentialist” approaches, which aim to minimise the negative impacts of scientific activity, including in science education (L. Bencze et al., 2020). Consequentialist approaches precede current epistemic positionings about science in society, for example, the RRI notion. This can be inferred by the fact that SSI as presented in this study could only represent epistemic visions of science that precede RRI.

1.3. Convey the interdisciplinarity of knowledge

The contribution of SSI-based instruction to the overall goal of introducing competences or contents from other disciplines in science subjects was analysed in this study. In particular, its connections with: 1) Science, Technology, Engineering and Mathematics (STEM) subjects, 2) Citizenship education, 3) Linguistic competence, and 4) Social science emerged.

Regarding STEM subjects, it was found that teachers see the fact that SSI involve content related to the science discipline that they teach as a valuable aspect, but these issues are also suitable for including content from other disciplines within the experimental sciences. For example, teachers developed the content from an SSI connected to physics with content from other disciplines such as technology. As for the relation between science and other STEM subjects, teachers establish stronger links between science and technology or engineering, than between science and mathematics, for example.

Regarding citizenship education, it was found that teachers see SSI-based instruction as a way of helping students become well-equipped citizens (Kolsto, 2001). In particular, they see SSI as a way to help students develop ownership and skills for making informed decisions in their real life and taking action. These results are positive for the widespread application of SSI-based instruction, especially in countries where decision-making has been introduced as part of secondary education, and in science education (Steffen & Hößle, 2014). Furthermore, it was found that although teachers emphasise making decisions at an individual level, they are aware that SSI are not isolated issues but aspects of global problems. Being a well-
equipped citizen involves making decisions at an individual level but that are nationally, locally, or globally framed, such as what type of bags to use for shopping. Therefore, this study suggests that SSI-based instruction can be a helpful tool for teachers to develop what is known as “Global competence” (Organisation for Economic Co-operation and Development, 2019), that is also present in European national curricula. This idea, to date, has been studied mostly in students, and it has informed the SSI lessons that are being developed for teachers (Bayram-Jacobs, Wieske, & Henze, 2019; Levinson & PARRISE consortium, 2017; Romero-Ariza et al., 2017). However, it had only been studied to some extent in teachers (Lee & Witz, 2009).

References to linguistic competence were also found to be prevalent, as represented by the following skills: communicating clearly, active listening, using the appropriate register and vocabulary. The main value that teachers see in SSI-based instruction for developing these skills is that it involves discussion. However, teachers recognise that they are not confident or trained in teaching these skills to students. The implications of this finding are that science teachers need more support in order to promote linguistic competence through SSI-based instruction.

Finally, SSI-based instruction has been shown to hold potential to establish connections between what is known experimental sciences and social sciences. Social sciences refers to a subject in secondary school that includes the disciplines of politics, economics, history, geography, sometimes in the same subject or as separate subjects. As it has been defined, SSI-based instruction makes it possible to introduce contents from these subjects into science class, such as policy-making or development of laws, global or domestic economics, international relations, commerce, etc. In this regard, it was found that teachers’ views can be located on a continuum, depending on the importance that they give to the social aspect of the SSI, like other authors have pointed out (Lundström et al., 2017). It was found that most teachers, rather than incorporating the social aspects in a secondary way, include them in the learning objectives, stress them in the development of the lesson, and assess them at least to a certain extent. This finding could be interpreted as evidence confirming that SSI offers teachers a unique and new approach to meeting the needs of teaching science in a world where science is developed in collaboration with society and must therefore incorporate a social perspective. This constitutes alternative evidence for previous studies indicating that teachers mostly used SSI to convey science content (Ekborg et al., 2013).
However, overall it was also found that when teachers refer to other disciplines, they always do so from their position as teachers of a discipline, i.e. general science, physics, chemistry, etc. They establish connections or create links between their discipline and others, but not at the same level. Considering the societal-cultural context where this research was developed, this finding provides evidence that when SSI are not supported by policy, curriculum or the school, their potential to break the disciplinary barrier is limited.
2. Dimension 2) Components of SSI-based instruction

This section discusses the results for dimension 2 of this study. This dimension sees SSI as composed by a set of components, which in this investigation are materialised in the following categories: a) methodological approaches, b) techniques for discussing SSI, and c) assessment. The results obtained for each component are discussed below.

2.1. Methodological approaches: Inquiry-Based Learning

As a result of the cross-case analysis, it was found that the SSI that teachers were exposed to in this research can be taught through an Inquiry-Based Learning approach. According to teachers, students can develop knowledge about the SSI by trying to answer a question through collecting and analysing data. For example, it is possible to learn about the SSI of developing a vaccine for a virus by analysing its risks and benefits based on available scientific evidence. The processes that students engage in are related to evidence-based learning such as “the scientific method”, or establishing relations between concepts. No questioning of this method was found in either of the two cases, and different SSI were taught through IBL. This evidence suggests that inquiry could be one methodological approach to solving the problem of keeping the SSI present throughout the whole lesson, so that teachers can provide what has been called full-fledged SSI teaching, not just as an introduction or a context to teach content knowledge (Tidemand & Nielsen, 2017).

Teachers in this research demonstrate good command and knowledge of IBL as a methodological approach. This finding suggests that if SSI are being taught with an IBL methodology, it may make it easier for teachers than if SSI are taught using other methodological approaches.

Regarding the stages of the IBL sequence, it was found that teachers understand and adapt its phases as a whole, without altering the sequence. However, some specificities were discovered within each phase. Teachers add more activities mostly in phases 1) Engage and 2) Extend. In phase 1) Engage, which consists in getting students acquainted with the SSI, teachers provide more information about the SSI, and typically choose video as the most common format. In phase 2) Extend, where students look for evidences to make a decision about the SSI, teachers add activities that are mostly interactive, hands on, and with the objective of deepening their understanding of specific aspects of the SSI. If teachers can add more activities while keeping the IBL sequence, it suggests that teaching SSI through the IBL
can be adapted to different educational levels and student needs. At the same time, the data shows that in this phase, collecting and analysing data about an SSI is not the same as for a scientific issue. Teachers talk about genuinely SSI-based instruction aspects such as considering multiple perspectives. This result may constitute validation of the existence of a unique teaching method for SSI known as socioscientific inquiry, which has been proposed as an effective way to teach SSI to students (Troy D. Sadler et al., 2017).

Regarding phase 3) Evaluate, where students synthesise the evidence collected and communicate their decision about the SSI, teachers stress the need to deliberate about the SSI in a scientific way, following the scientific conventions in a science lesson that is structured around an SSI, guided by objectivity, rationality and balance. This result is consistent with the methods and knowledge that students draw on when making decisions about SSI in science class, according to previous research (Kolstø et al., 2006). Therefore, it shows that IBL conveys this understanding.

In this phase, some teachers add students’ creation of a learning product. This shows that IBL, in practice, is mixed with components from other, similar methodological approaches such as Project-Based Learning (PBL). A misunderstanding was observed, especially in case 1, of the meaning of the phase 3) Evaluate. Some teachers mistook this phase for one during which student learning should be assessed, whereas assessment can take place throughout the whole process. This may mean that, in practice, this phase of the inquiry sequence into SSI is not considered as important as the previous ones. This could be due to the fact that science teachers may be more familiar with the process of data collection and analysis (i.e. phase 2) Extend), than with the process of communicating the results of an enquiry.

The analysis of the data also revealed that teachers see IBL mainly as a way to collect scientific evidence about the SSI, and make a decision based on analysing that evidence scientifically. In teachers’ minds, as a result of inquiring about the SSI, all students will reach a similar conclusion, while not necessarily following the same inquiry paths. This makes learning about the SSI more meaningful and active than other methods such as direct instruction, and thus, more effective. However, one characteristic of SSI is that the scientific claims they are based on are under discussion. This suggests that IBL is more suited to SSI whose scientific claims garner greater consensus in real life, for example that it is necessary to reduce plastic consumption. For this case, teachers will be comfortable guiding students through the IBL experience where they collect and analyse evidences to reach a similar conclusion. Other SSI, whose claims are less clear, will create tension with the IBL methodology for these teachers.
This suggests that some SSI will be a better fit for the teaching style of science teachers than others.

Regarding the openness of the inquiry process, it was found that teachers mostly provide teacher-led inquiry. This is an expected result seeing that teaching SSI is new for these teachers, and probably the students. Thus, they want to provide students all the resources and keep the class “under control”. Only weak evidences were found that teachers use open IBL where students ask their own questions, look for data sources, etc. and they correspond to teachers who seem confident and more experienced in these types of methodological approaches.

2.2. Techniques for discussing SSI

2.2.1. Dilemmas

As a result of the analysis, the reasons why teachers think the dilemma is a good technique to discuss SSI were elicited. First, teachers highlight that the dilemma asks students to take a position on the SSI, which they see as valuable because it makes students take an active role in their learning. More specifically, presenting the SSI as a dilemma requests students to draw on their existing knowledge and values, thus making learning more meaningful and personalised, which teachers see as promoting learning. In this understanding, the dilemma is useful for collecting information about students’ starting position, and building on them throughout the lesson. Second, teachers associate the dilemma with the need to make a decision about the SSI. This active role of students is highly appreciated, since students become involved in making a decision about a real issue. This process empowers students with a sense of ownership. Teachers appreciate these aspects as a way to learn about the SSI.

Another finding in this category is the misconceptions that teachers have about the dilemma. One misconception concerns the difference between a dilemma and scientific controversy. Teachers propose to engage students in the social, political or economic aspects of a scientific issue, with an emphasis on its controversial aspects. This means that dilemmas are not considered necessary for some teachers to have students engage in SSI, but rather the fact that it is controversial is sufficiently engaging. Another misconception was to mistakenly conceive of the dilemma as a decision reached following argumentation about the SSI in a classroom setting. This understanding of the dilemma reduces the potential that the dilemma
itself can bring about engagement in an SSI by considering alternatives that are both desirable and non-desirable.

Finally, regarding the alternatives that the dilemma proposes, it was found that teachers tend to present one alternative as better than the others. Some teachers do this explicitly, others implicitly. This could influence how students engage with the SSI because they may be inclined towards the alternative that they perceive as “correct” because it is suggested by the teacher.

### 2.2.2. Group discussion

#### 2.2.1. Students’ use of knowledge about the SSI in group discussion

The analysis of the two cases revealed how teachers facilitate student application of knowledge about the SSI when it is approached through a group discussion. The most common view sees group discussion as a vehicle to make sure that students develop sufficient and solid knowledge about the SSI, given the need to present arguments and defend a position in the discussion. In this light, teachers see group discussion as an “enactment” of knowledge that students have previously developed about the SSI. The knowledge that teachers mention is mostly scientific content. Therefore, it was confirmed that teachers share the theoretical idea that a group discussion about an SSI is not just about students expressing their own views and opinions, but also includes using scientific claims sustaining the SSI, etc. Some teachers go a step further and see group discussion as a way for students to have their knowledge about the SSI challenged. By listening to their peers’ arguments, students update or confirm their claims about the SSI.

This shows that a technique that is thought to engage students with the SSI can become a methodological approach in itself, where students collect evidence to decide about the SSI, following an IBL approach. This result could be seen as positive because it opens the potential for group discussion to become a methodological approach for learning about SSI. However, if teachers focus on the claims that students use in the discussion, instead of the arguments supporting them, the potential of group discussion for helping students to develop sufficiently strong justifications for their claims about the SSI may be missed, which is a key affordance of group discussion when applied to SSI (Bossér & Lindahl, 2020).
2.2.2. Rules of group discussion

It was found that for teachers it is of extreme importance that before students engage in discussion about an SSI, the rules for the discussion, as well as their roles, are clear. Teachers make groups of students for discussion on a voluntary basis, or according to how students are seated, as opposed to their academic level or motivation towards learning. However, some teachers recognise that they should think of a different way to group students because it could bring benefits for the classroom environment and student learning. This shows that teachers do not have specific criteria for organising a group discussion about an SSI; it is pragmatic rather than focused on how to facilitate discussion, and it is decided on the spot.

2.2.3. Managing group discussion

It was revealed that teachers have experience in managing group discussions with their students, but not on SSI. As reported by some teachers in case 1, teachers use group discussion in “tutoría” (tutoring); this is an hour devoted to solving social conflicts in the group class or addressing issues of convivence at the school. In other words, teachers already have experience with group discussion as a methodological approach, but they do not think to use it in their science class. This could influence how group discussion is delivered when used for SSI: teachers who have this experience will be more familiar with students expressing their views in SSI-based instruction.

The data analysis indicates how teachers face and address common problems regarding student engagement in the SSI through group discussion: lack of student participation, deviation from the topic, and chaos or disorganisation.

The problem of “quiet students” is the one that concerns teachers the most, and they think it is due to two main reasons. One reason is the dynamics that already exist within the group of students, where there are some students who are most confident or active in class and who take up all the “talking” space. In other words, teachers are confident that discussions are a good way to engage students; this means that they want to participate, but cannot. Accordingly, they report devoting time, efforts and resources to engaging students in discussion and balance out student interventions. These may include prompts, regulating the right to speak, or creating smaller groups of students for discussion. Regarding the last, teachers think that in a smaller group, the quiet students will feel more pressure and may participate more in the discussion. Other reasons concerning why students may be quiet
during group discussion about SSI, such as not being interested, or not having the skills, were not given sufficient attention by the teachers participating in this research.

In terms of deviation from the topic, teachers mostly blame students for this. It was found that students bring new information to the discussion and ask questions. This is less frequent in teachers who practise a teaching style that is generally more teacher-led and which makes students less likely to deviate from the topic.

Among teachers who experience this situation, however, it was found that it creates a tension where they have to choose between giving free rein to the students at the expense of abandoning the planned learning goals of the lesson, or keeping students on track in discussing the aspects of the SSI that were initially planned. Most teachers end up prioritising students' interests than their goals for the group discussion, and a few factors were identified that influence their decision. First, the pressure of university entry exams to cover as much content as possible in higher levels of secondary school may make teachers less interested in following students' interests, and focus strictly the initial plan for discussion. Therefore, teachers at lower secondary school levels will accept more deviations from the topic than those at higher levels. The second factor is teachers' expectations about the group discussion. Some teachers are happy to discuss the SSI in a superficial manner, as some sort of brainstorming. The extent to which engagement with the SSI takes place through the discussion is not so important for these teachers, but the very fact that they discuss the SSI. Finally, their perceived ability to bring students back to the topic influences how they manage this issue.

Finally, teachers describe the problem with managing group discussion known as chaos or disorganisation as students not listening to each other, talking over their peers and becoming too vehement in their arguments. Organisation, calm and structured discussion seem to be related to the need for group discussion to be productive. Although teachers “place the blame” for this problem on students, they recognise that the role of the teacher is key to avoiding this chaos and disorganisation. This means that for teachers, managing the group or making sure the discussion goes smoothly is a bigger concern than how students interact with the SSI. However, they do not feel sufficiently skilled to do that. The implications of this finding are that if SSI-based instruction is to be promoted and supported, teachers need skills that help them overcome their fear of chaos or disorganisation in group discussion as a technique to discuss SSI.
2.3. Assessment

2.3.1. What is assessed

It was found that teachers are inclined to assess the content knowledge aspects of the SSI. They mention techniques for assessing it in connection with the learning objectives of the lesson. This is a common and usual object of assessment for science teachers that is determined by the curriculum. Thus, it was demonstrated that the SSI proposed can be assessed by using indicators and items that are established in the curriculum for this educational level, and it suggests that the link between SSI and science assessment items is key for teachers.

Nevertheless, teachers also collect assessment evidences about other aspects. They assessed student skills, mostly related to the discussion nature of the SSI such as: weighing risks and benefits, providing solid arguments that justify a position, and considering uncertainty. This suggests that teachers assess student learning of SSI in a different way than other scientific content, with unique assessment items. Moreover, these three aspects have strong parallels with the items assessed in the QUASSR instrument, which is an empirical tool used to evaluate student competences in dealing with SSI (Romine, Sadler, Dauer, & Kinslow, 2020). This suggests that this research tool would be useful for teachers to gain feedback about student learning of the SSI that were proposed in this research.

It was found that some teachers assess students’ learning process. They mostly focus on collecting evidence about student participation in the lesson. The aspect that teachers are most interested in is discussion about the SSI, where they mainly check formal aspects, including showing respect for the opinions of others or active listening.

2.2.2. Assessment strategies

The main finding regarding who performs assessment is that the majority of teachers assume that they are in charge. Only very few references were made to students assessing their own learning. Teachers demonstrate ownership of assessing student learning in different ways. They choose what is to be assessed, which criteria or indicators are going to be used, and they determine when to perform assessment. They use a diversity of techniques, which include observing, listening, or taking notes about what students do throughout the lesson,
which they grade using rubrics. Teachers seem comfortable and confident in this task, as long as they can collect data that matches the curriculum contents or performance indicators.

Self-assessment does not seem to be the main way to assess learning about the SSI. The teachers who consider it do so because it has been part of their teaching practice and claim to have experience in making students aware of what they have learned.

It was found that it is important for teachers to collect students’ individual learning evidences in SSI-based instruction. This is a specificity in SSI compared to teaching other content because SSI involve discussing points of view and arguments, and it is difficult for teachers to gather information about how each student engages and negotiates with the different arguments. To address this need, teachers mostly propose that students create a learning product. The learning products that teachers collect are mostly written reflections that summarise the points that were made about the SSI and a personal conclusion.
3. Dimension 3) Resistance to SSI-based instruction

The third and last dimension of SSI-based instruction, when used as an educational innovation, is the resistance to it. This aspect has been researched in dimension 3 of the present research. This section provides a discussion of the results for such dimension, as per the sources of resistance that were researched: a) students, b) content load, c) organisation, schedule, timetable, and d) teachers' choice of the SSI. The results obtained for each category are discussed below.

3.1. Resistance on students

3.1.1. Student participation

This study provided information about student participation as a resistance to SSI-based instruction, as perceived by secondary school science teachers. The factors that emerge which affect student participation are: 1) student awareness that they must participate; 2) students' willingness to participate, 3) students' previous experience participating in science class.

With respect to the first factor, teachers mostly establish a comparison between teaching SSI and teaching other curricular content. The data shows that teachers recognise that students have a more active role in their learning; they are more empowered when they learn about an SSI than other content, as expressed, for instance, in considering contradicting or conflicting claims, or taking a position on the issue. Because teachers are aware that this is an important aspect for the success of SSI-based instruction, they devote classroom time to making students aware that they are required to participate. More specifically, the techniques they use are implicit, as opposed to the teacher “asking” students to participate. Role play is a technique that teachers use to achieve student participation in SSI lessons.

Teachers give two main reasons for student willingness to participate in SSI-based instruction: the interest they have in the SSI and their general motivation towards formal education. It was observed that teachers expect a great deal from SSI as a way of promoting student participation. This assumption can be seen as overly optimistic considering how diverse students are in secondary school, where each adolescent has different interests. This suggests that in practice, teachers would have to invest time in finding out which are the most attractive SSI for the majority of students, or in making all students interested in a
specific SSI before actually delivering SSI-based instruction. Regarding student interest in formal education, teachers imply that students who are most motivated towards learning science are more willing to participate in an SSI lesson than those who are not.

Concerning the third factor, teachers working with students who have experience in participating in science class are more confident in achieving student participation. It has been empirically demonstrated in other contexts that teachers believe that students’ lack of experience in learning SSI affects their involvement (Ekborg et al., 2013). This research, thus, adds a new layer which is student participation in the lesson where they learn about an SSI. The techniques that teachers mention using are: asking their students to express their opinion in science class, or discussing social problems at the school. This suggests that other innovations or changes in teaching methodologies in secondary school could facilitate the implementation of SSI-based instruction, as students progressively become more used to participating in class.

3.1.2. Personal involvement in the SSI

It was found that teachers invest time and effort to overcome the resistance of students to become personally involved in the SSI. They use different techniques. One is to make the issue relevant for students' value system and the most immediate implications for their daily lives. In this case, the problem teachers encounter is that students may get too emotional or vehement about the SSI and this distracts from learning scientific facts or considering the SSI in a scientific way. Discussion appears to be a way to solve this problem. If students have to develop discussion skills, they will be able to express their opinions in an articulate way, listen to others, and question what they think about an SSI as a result of addressing it in science class. Other teachers achieve personal involvement in the SSI in a more rational way, mostly by asking them questions such as “what is your opinion”, or “how do you think this should be done”.

Regarding this sub-category, it was also found that teachers invest a lot of effort in this at different points during SSI-based instruction. The most common tendency is to try to achieve student personal involvement at the start of the lesson, and then use this involvement to get them to do the “serious” work.
3.2. Resistance on content load

Different strategies were identified for making SSI-based instruction compatible with teachers' need to teach the science curriculum. One approach is to cover as much curricular content as possible during SSI-based instruction. The analysis of the two cases demonstrated that in addition to teaching the SSI, teachers include other curricular learning goals or insert more curricular content. Another approach is not to teach SSI on a regular basis, but as a dedicated, self-contained activity. Teachers consider SSI-based instruction as a complement to the way they usually teach, mainly because it requires a lot of time to complete compared to teaching other content. In this sense, it poses a dilemma for teachers, who see SSI-based instruction as “taking time away” from their usual teaching while presenting many advantages, especially the fact that students are engaged. The cost and benefit, thus, depends on the frequency of using SSI-based instruction in relation to the results obtained. In general, teachers think it is worth it to the extent that it increases student motivation, and it gives teachers satisfaction to feel they are introducing something new for their students. It seems that occasionally teaching SSI is worth it for teachers because it helps them to get students “on board”. The drawbacks are that once the novelty has worn off, students may find it hard to stay motivated about learning science. Indeed, previous studies suggest that science teachers’ use of SSI to teach scientific facts and principles is easier for teachers where SSI are supported in the curriculum (Tidemand & Nielsen, 2017).

This could be interpreted as a contradiction on the part of policy-makers, who promote learning of current, relevant social topics in science class without reducing content load. Moreover, it brings up a debate about what SSI to include in the curriculum, seeing that the perception of what constitutes an issue depends on society’s values.

However, it is also true that in Spain, teachers do not receive much pressure and are not monitored to check how much of the curriculum they cover. For this reason, this view could be explained by other factors such as the strong personal attachment of secondary school teachers, and especially science teachers, to teaching content. Teachers just “complain” about the content, but they do not provide much more information about how it clashes with SSI-based instruction. It seems that some teachers are very attached to the curriculum and hence believe that SSI are “taking away” time from their lessons, as demonstrated in other educational innovations, for reasons that go beyond the nature of SSI-based instruction. If true, it would mean that the pressure of the curriculum is rather perceived than real for these
teachers. The implications of this finding for maintaining and supporting SSI-based instruction is to make this explicit for teachers, and this could be achieved through initial or in-service teacher PD. Other, currently happening changes informal education are expected to help overcome this resistance such as including SSI in the curricula. Indeed, the Spanish curriculum includes certain SSI, although in a very granular way, and these are not supported by assessment items (Vázquez-Alonso & Manassero-Mas, 2016).

3.3. Resistance on organisation, schedule, and timetable

A common trend in both cases was that to teach SSI, more time is needed than just one lesson, which normally lasts for one hour. Teachers who experimented with an Engage material and wanted to keep it restricted to the duration of the one-hour lesson skipped activities, rushed to the end, or did not address the issue in depth in the way they would have liked. Teachers feel they do not have enough time because SSI require the use of additional materials such as videos, and presentations, which present additional technical work. Furthermore, SSI-based instruction involves discussion or students working in groups, all of which are time-consuming activities compared to direct instruction.

However, this outcome does not mean that teachers do not want to deliver SSI-based instruction again. On the contrary, they find solutions, for example delivering SSI-based instruction in split classes or taking time from other lessons that they teach. Other teachers chose to split teaching about an SSI in two lessons. This finding suggests that teachers are willing to do changes to make SSI-based instruction fit into the organisational aspects of secondary school.

At the same time, the need for more time for SSI-based instruction conflicts with the fact that secondary school teachers provide instruction as part of an organisation (the school) that requires them to keep their lessons to one hour, a requirement imposed by higher levels of school hierarchy. Different ideas emerged to overcome this difficulty. Some teachers suggest solutions that are within their control, such as using a split class or asking students to do part of the lesson at home, using time that they would otherwise use for experiments. Other teachers suggest actions that go beyond their field of action, such as getting in touch with teachers from other subjects to discuss ways of using time differently. In both cases, no mention was made to working at with student heads or school managers, thus suggesting that in teachers' opinion it is possible to deliver SSI-based instruction without altering higher levels of school hierarchy.
3.4. Resistance on teachers’ choice of the SSI

It was found that the main reason why teachers choose to teach an SSI in class, in addition to the link with the subject they are teaching, is student interests. They put students in the spotlight over other reasons such as how current the SSI is, or how close it is to their local reality. To achieve that goal, teachers mainly observe students at and outside of school, trying to identify what affects them and the stories they may hear about through the media they consume in their free time, such as television or the internet.

In this regard, it was found that in teachers' understanding, the most interesting dilemmas affect students directly or the things they care about. However, what commonly interests students is not what the teacher expects them to be interested in. This is reflected in the lesson, where students' interest is not always very high, and when it is, it does not last as long as teachers expect, like a “novelty” effect that fades as the lesson progresses. This poses a challenge to developers of educational materials to support SSI-based instruction. As expressed by Ekborg et al., (2009), SSI cannot be provided to teachers, for example in textbooks, because they will be outdated by the time they make it to class. They will still be applications of science to real life, but they will not be currently discussed nor will they necessarily be debated on a social level by that time.

Finally, it was found that if teachers choose SSI that affect students too directly, the appeal of the issue may make it difficult for students to approach it scientifically. This may make teachers who are not very confident in their ability to manage SSI-based instruction reluctant to bring really meaningful SSI to class to avoid this challenge.
CHAPTER 6

CONCLUSIONS
Chapter 6: Conclusions

The last chapter of the present dissertation is concerned with the conclusions of the study. It synthesises its main findings on the basis of the results obtained, thus responding to the objectives of the investigation. To achieve that goal, the first section of this chapter provides answers to the research questions. The second section is concerned with the limitations of the study. Then, the implications that emerge from the findings are discussed in this chapter. The last section in this chapter presents future lines of research that emerge from the study.
1. Answers to the research questions

This study is an attempt to describe, characterize and understand secondary school science teachers' professional practice in the context of an educational innovation in the science teaching and learning process. More specifically, the study aimed to develop an in-depth understanding of how teachers deliver Socioscientific Issues (SSI)-based instruction (Davut Gul & Akcay, 2020; Lee & Yang, 2019; Presley et al., 2013; Troy D. Sadler et al., 2016). SSI are social issues with a connection to science that are relevant in a societal context at a given time. SSI-based instruction has been defined as a unique and new teaching practice (Owens et al., 2019; Zangori et al., 2018).

When used as an educational innovation, SSI-based instruction aims to bridging a gap between how science is taught in secondary school and the need to helping students develop a scientific competence that equips them to develop a conscious, active and responsible citizenship (Díaz-Moreno et al., 2019). In this specific context, SSI-based instruction holds potential to bridge this gap while a higher level reform that makes formal science education keep up with these societal needs takes place.

It was found that several threats affect SSI-based instruction when it is used in this way, one of them is teachers' incorrect or inaccurate use of it (Ekborg et al., 2013; Kilinc et al., 2017; Tidemand & Nielsen, 2017). Therefore, a need was identified in the literature to support, maintain and facilitate teachers' delivery of SSI-based instruction. To that goal, educational research has focused on characterizing this educational practice. However, few studies characterized the phenomenon in a comprehensive way.

To develop an understanding of SSI-based instruction as an innovation that aims to bridge the gap between how science is taught at school and students' needs, this qualitative, interpretivist study collected data from Spanish in-service science teachers who planned, adapted or implemented one or more SSI materials. SSI materials are self-contained curriculum units that aim to teach students about one SSI.

Multiple case study design was deployed. Case 1 was a group of teachers who enrolled in an online professional development (PD) course where they planned, implemented or reflected about SSI materials. Case 2 is composed by a group of teachers who adapted and implemented one SSI material of their choice.
Although this study collected data from teachers, it is different from other studies that assess educational interventions such as for example Professional Development (PD) programmes for teachers to promote SSI-based instruction. Those studies measure the impact of the programmes on variables such as teacher motivation, as well as teacher development of new knowledge, for example (Saunders & Rennie, 2013). Instead, in this study teachers’ practice of SSI-based instruction is seen as a phenomenon occurring in those contexts of educational innovation and it aims to describe the phenomenon.

Data was collected through qualitative instruments, including open ended questionnaires to teachers, observation of their participation in an online course, and observation of classroom implementation of SSI materials. Their responses were analysed following an interpretative framework that was built on the basis of previous literature about SSI-based instruction. The framework adopted a multi-dimensional approach to educational innovation, where the phenomenon of SSI-based instruction was approached from three dimensions: D1) Objectives of SSI-based instruction, D2) Components of SSI-based instruction, and D3) Resistances to SSI-based instruction. Cross-case analysis was performed as a way to develop knowledge about the phenomenon. More specifically, content analysis was performed and supported by a qualitative analysis software.

This study aimed to answer a main research question (RQ): How do secondary school science teachers deliver SSI-based instruction, as a way to innovate in their practice? As a way to answer the main research question, sub-questions were formulated. This section presents the answers to the sub-questions (SQ1, SQ2, and SQ3) and to the main research question (RQ).

1.1. SQ1: To what extent do teachers think that SSI-based instruction is a way to help students develop conscious and active citizenship in science education?

As an answer to SQ1, it was found that teachers associate SSI-based instruction to a view of formal science education which, instead of transmitting factual scientific knowledge, is focused on how it is applied in specific contexts and problems. For teachers, SSI-based instruction meets a belief they have that science education is too abstract, includes too much scientific content that is not easily related to any problem, situation or phenomenon that is necessary to understand to get by in our current society. As a way to better understand this
belief, two findings emerged that provide rich answers to this sub-question, and are presented as follows.

1.1.1. An emphasis on explaining phenomena scientifically

Scientific literacy is the main purpose of formal science education, and as it is defined in national curricula and international assessment tests it reflects the need for students to develop an active, conscious and responsible citizenship. As it is defined nowadays, it involves being competent in a) explaining phenomena scientifically, b) evaluating and designing scientific inquiry, and c) interpreting data and evidence scientifically. It was found that teachers mostly see SSI-based instruction as a way to contribute to student development of the scientific competence "explaining phenomena scientifically".

This finding means that among the three ways to be scientifically competent and therefore responsible citizens, the contributions of SSI-based instruction that are most clear to teachers is as a way to enhance student understanding of issues of global reach. In other words, teachers see SSI as real world problems that students must know about, equally worth teaching as the traditional contents. In particular, teachers are interested in the issues that have high impact in our lives, such as those related to health and environment. It seems that teachers' understanding of science education for a responsible, conscious citizenship is restricted to the vision of a society where science and technology play a higher role in our daily lives, thus skills are necessary to be able to understand science and participate in scientific and technological processes, as a new way of literacy.

Moreover, the analysis of teachers' mention to skills that are necessary in this process confirm the existence of unique skills that teachers associate to SSI, such as uncertainty of the scientific process, considering nuances when making scientific statements, etc. These are all consistent with student competences specifications such as the construct SSR that was introduced in Chapter 2: Theoretical framework. The association between SSI-based instruction and students' skills can be seen as an enabler to the implementation of SSI-based instruction when it is used as an educational innovation, this is, when it is not supported in the curriculum, because teachers are convinced that students need to develop these skills.

Although to a lesser extent, the affordances of SSI to help students develop the competences "evaluating and designing scientific inquiry", and "interpreting data and evidence scientifically" were also represented in the data. As for the first, the main contribution of
SSI-based instruction focusses on effectively conveying students the need to ask researchable questions. According to teachers, this skill helps them to be active and involved citizens of today. Regarding the second, teachers see SSI-based instruction as a way to help students develop the skills to develop knowledge from scientific data. In their minds, this is a useful skill that will make them independent and empowered.

### 1.1.2. SSI as part of the knowledge society

Evidence has been found in this study where teachers refer to the fact that information is increasingly abundant, open and easily accessible nowadays. This leads not only to a saturation of information, but to the need for skills to develop knowledge from all that information. In teachers' understanding, this process includes making sense of the natural world from the information that is available through the Media. They see SSI-based instruction as a key opportunity to help students develop the skills to develop well-grounded knowledge by learning how to manage and assess the quality of scientific information, as a response to a need they observe in students, which is the tendency to believe and spread any scientific or scientific-looking information they receive, not questioning it.

Teachers think SSI-based instruction is valuable because it engages students in processes involving analysis of scientific information, critical thinking, and decision making based on argumentation. This finding opens up possibilities to deepen and maintain SSI-based instruction in science education in the light of the increasing trend in the last decades towards disseminating and transferring the results of science and innovation to society through science outreach programmes, science communication, open science policies or social media. this trend should provide teachers with more ideas of SSI to bring to the classroom, and easier access to information about them.

However, the view that teaches' hold about citizenship in the context of the knowledge society, and the process of making sense of reality as part of a communication system is limited. Consuming scientific information and making sense of it is just one part of active, conscious and responsible citizenship. The other part is creating and contributing to it. Very little evidence was found in this investigation where teachers see SSI-based instruction as a vehicle to help students communicate their understanding, positioning or views about scientific topics in a context of a global discussion, beyond a "simulation" in a class activity.
1.1.3. A discussion about the purposes and processes of scientific activity

One of the key points of active and responsible citizenship refers to the relation between citizens and scientific activity. As part of today’s society, being an active citizen means knowing that science is a human activity and that citizens have something to say about how it is developed, what research lines are prioritised, etc. It was found that teachers share this view, but only to a certain extent. There is a gap between the current approach to developing science (as expressed in RRI policy) and what teachers think of science as a human activity. Teachers ideas predate this model and correspond with early visions of policies of citizen engagement in science, as expressed in concepts such as an awareness of the consequences of scientific products to be used or adopted by society. Teachers do not emphasize other possible implications still linked to science being a human activity, as it could be the fact that it is fallible. In this sense, teachers conceive SSI-based instruction in a way that is closer to previous, context-based science learning approaches, such as STS/E.

1.2. SQ2: How do science teachers develop SSI-based instruction as part of a lesson?

Sub-question SQ2, which was posed in this study as a way to answer the main research question was formulated around the concept of lesson. Lessons are a key component of secondary school science teachers’ professional practice: they plan them, deliver them, and evaluate them. The main trends that emerged in this dimension are summarized in subsections below.

1.2.1. Adaptation and development of the IBL methodological approach

One of the essential components of a lesson is the methodological approach, which proposes a way to facilitate student learning. Inquiry-Based Learning (IBL) was not hard to understand for science teachers in the specific case of SSI-based instruction, who seem to be familiar with it. However, a trend was found where teachers misunderstand phase "3) Evaluate" for assessment of student learning. Phase "3) Evaluate", in contrast, consists of students' weighing of the points of view about the issue in order to make a reasoned decision, which they communicate to the teacher or their peers. This misunderstanding is a risk for lessons
that use SSI-based instruction, because students will be missing a step of the inquiry process that corresponds to a closure of the process of learning about the SSI.

Strong relations were found between IBL and the scientific method, which teachers are very interested and have experience in using in their lessons. This suggests that the choice of IBL as a methodological approach for SSI-based instruction will facilitate that it is used in teachers who can understand or have experience in using IBL. It was also found that teachers' interest and belief in the scientific method as a way to construct reliable knowledge is associated to procedures such as objectivity, reducing uncertainty, and scientific argumentation. Teachers do not leave much room for subjective arguments, opinions, or considerations of other sort other than scientific as part of inquiring about an SSI. This result can be interpreted in the light of in-service teachers' initial training, which is mostly disciplinary and not necessarily aligned to current views of the scientific process as developed according to societal values. This fact can be seen as a threat to SSI-based instruction but that it can be overcome as soon as the new view of the scientific process is incorporated in initial teacher education.

Further, it was found that the 3E inquiry model allowed to cater for the needs of different teachers and students, where the most common adaptation was to add learning activities. The activities were added mostly in phase 2) Extend, and are mostly oriented to deepening students' knowledge about the SSI. This finding confirms that one of the main developments that teachers do to SSI-based instruction when applied to a lesson is adding more core learning activities, as opposed to activities of exploration of previous knowledge or evaluation activities. This finding may suggest that teachers consider insufficient the data collection about an SSI as useful for students to learn about SSI, and that they trust other techniques as effective. In practical terms, if teachers increase the number of learning activities, even within the 3E inquiry model, more classroom time will be devoted to SSI-based instruction. The need for more time may clash with the fact that in secondary school, lessons generally last for an hour.

Moreover, it was found that the learning activities that teachers add to the existing 3E inquiry sequence mostly consist of association activities, analysing, or establishing relations between concepts. These activities are associated to Higher Order Thinking Skills (HOTS), which is a priority in secondary school, as stated in the curriculum and in educational policy. For this reason, teachers' development of the inquiry sequence in this way can be considered an
enabler to the implementation and widespread use of SSI-based instruction in science education.

Finally, as a result of this investigation it was confirmed that teachers see IBL as a way for students to reach their own understanding about the SSI on the basis of their individual inquiry. However, a tension was found between this aspect and teachers' will that all students reach the same understanding of the SSI.

1.2.2. Student engagement in the lesson

Student engagement in the learning activity is key for the success of SSI-based instruction because SSI are related to students life in different ways: they deal with phenomena that they encounter on a frequent basis or whose evolution has consequences in their immediate life or the life of close relatives or friends, they appeal to their value system or beliefs, they represent a threat, or more than one of these reasons. For this reason, SSI are expected to be meaningful for students, and if they are meaningful, students will become engaged in the lesson. However, there is a lack of understanding of how teachers work towards achieving genuine, sustained engagement in learning SSI as part of an academic activity in secondary education.

It was found that teachers invest efforts and resources to promote and maintain student engagement in the lesson. The main way that teachers do so is by preparation, i.e. ensuring that the SSI is appealing to students. Teachers think that the main reasons why an SSI is appealing to students is because it affects them or has consequences in their close environment, for example health-related issues. In this sense, it was found that they assume that an SSI will be more interesting or appealing to students than it really is. It was also discovered that although teachers put students' interests in the first place when planning SSI-based instruction, they often use other reasons to choose an SSI. These include their own interests, or how worthwhile is to address the SSI in their opinion, or how the SSI fits with the curriculum content that is being covered at a given moment.

Teachers' reports from using SSI materials in class indicate that the most effective SSI in terms of student engagement are those that are directly related to a real controversy, a decision or a conflict that has taken place or is taking place in students' life at school or outside of it. However, it was found that an interesting or appealing SSI is not sufficient to achieve student engagement in SSI-based instruction for the whole duration of the lesson,
but that other ways should be found, it must be done in a more structured manner. The techniques that work best are to make sure that all students have sufficient starting knowledge, asking students individual questions, assigning roles to students, and collaborative activities in small groups.

1.2.3. The importance of discussing SSI

Discussion emerged as a key component of SSI-based instruction for teachers. A tension was found between the potential of discussing SSI and a formal learning setting. Group discussion is, as such, a non-structured, open way of interaction that may involve students' attachment to their own opinions, vehemence when talking, difficulties in listening and in general keeping a calm and structured discussion. In contrast, teachers see discussing and providing arguments about an SSI is seen as an academic activity, where the arguments are presented in a structured and rational manner. This situation creates a tension for teachers, who will mostly use discussion about SSI with students who have the skills to do so. This may generate an unequal, uneven distribution of SSI-based instruction when teachers are left to their own devices to implement it. At the same time, it creates an opportunity to work on students' linguistic competence and skills, either in science class or in other subjects.

It was also found that teachers are not very experienced in structuring and managing a discussion in science class. They are more concerned and pay more attention to the formal aspects of discussion (respecting the right of speak, active listening, not interrupting) than to the actual content of the discussion. In practical terms, this means that they will be missing the opportunity to work on aspects that can be addressed genuinely with SSI such as the trustworthiness of a claim, etc.

1.2.4. Assessment, a challenge to overcome

It was found that teachers do not have a systematic approach to assessing student learning when SSI-based instruction is applied in a science lesson. Most teachers state that a lesson is successful as long as students reach the learning objectives, but they do not propose exhaustive or systematic means to gather such data. Instead, they rely on subjective measures such as observing student engagement with the SSI, or participation in the discussions. The lack of importance that teachers give to assessment indicates that they do not see SSI-based instruction as a structural innovation, but as an experimentation or test with something that
is not meant to last. Therefore, for deepening and extending SSI-based instruction, efforts should be made to develop systematic assessment tools, or help teachers develop their own.

A tension was identified between assessment of individual student learning and the need for teachers to provide a learning experience where students engage in dialogue with their peers. Teachers solve this problem by planning students' creation of individual learning products, the most common being an essay where students explain the decision they have made about the SSI and the arguments or points of view that they base their decision on.

1.3. SQ3: Which opportunities are there for SSI-based instruction, and which challenges does it face in secondary school science teachers' professional practice?

One way to understand how teachers deliver SSI-based instruction as an educational innovation is to consider the obstacles and challenges that it faces. This view starts from the assumption that any educational innovation is inserted in a system that already exists, in this case secondary school science teachers' professional practice. How SSI-based instruction fits into this has been studied, but not systematically. Sub-question SQ3 aimed to gain understanding about this perspective, and the themes that emerged as a way to answer this sub-questions are detailed below.

1.3.1. An opportunity to teach procedural and epistemic knowledge, in addition to content

Science teachers' pedagogical tasks is shaped by the need to help students develop knowledge, skills and attitudes about a science discipline. This task is known to conflict with educational innovation when it simply adds new content to the already existing, usually dense curriculum. Previous research showed that teachers' think of SSI as a means to teach content knowledge, namely scientific facts and principles. The present study provided nuances to these statements. Some teachers consider SSI as the objective of the lesson, thus opening up the possibility for SSI to be a curriculum content worth addressing for teachers. This demonstrates the power of SSI to promote a change in educational practice in countries where content may or may not be covered in the curriculum, at least until a wider educational reform, probably affecting the curriculum, incorporates SSI. Moreover, the present investigation added that that teachers did not have difficulties in establishing relations
between the SSI proposed in the Engage materials and the content of their discipline, and that when teaching SSI they established relations between different content items.

At the same time this study provided proof that teachers appreciate SSI-based instruction as a way to teach procedural and epistemic knowledge, including discussions about the purposes and consequences of scientific activity and uncertainty. If not counter-evidence for teachers' use of SSI-based instruction as a way to teach scientific content in context, this study provides some evidence that one of the benefits of SSI-based instruction is that it makes it easier to teach these aspects in science class.

1.3.2. A positive attitude towards SSI-based instruction

SSI-based instruction is being promoted in science education on the basis of its benefits for students. In these cases, teachers' attitude towards the innovation is one of the factors that determine to what extent and how they will deliver it in practice.

The teachers who participated in this research showed a generally positive attitude towards SSI-based instruction as a way to facilitate student learning. These include: greater student engagement with learning science, and the feeling of teaching science in a way that is more consistent with students' needs to navigate society nowadays. Teachers frequently criticised abstract science instruction as a suitable way to teach science, which according to them leads to student lack of motivation. SSI represent a new way to teach science, which is more applied to solving problems, and which teachers seem to consider more suited to a vision of formal science education based on competencies, performance oriented, and more consistent with the scientific problems that citizens encounter. Teachers find ways to overcome organisational limitations to the application of SSI-based instruction such as the restricted length of science lessons.

1.3.3. The costs and benefits of SSI-based instruction for teachers

Despite teachers' positive attitudes towards SSI-based instruction, it was discovered that how much they deliver it in practice depends on their subjective evaluation of its costs and benefits. The costs include preparation time, risk that it does not go well, among others; whereas the benefits are mainly stated as student learning and student motivation in the learning experience.
For most teachers, the costs overweight the benefits of SSI-based instruction. In particular, it was found that their assessment of students' skills to engage in the activities proposed by SSI-based instruction played a crucial role. Teachers who think their students are ready to engage in SSI-based instruction demonstrate practising it more often. They are confident that their students can follow an IBL sequence to learn about the SSI where they try to answer a question by collecting evidences, but they are not so confident about the skills that their students have to engage in a productive discussion. Similarly, their perception of their own skills was included in this equation. In particular, those who declare having used the debate in science class are more confident to use SSI-based instruction.

Regarding the benefits, teachers are looking for short-term, immediate results, especially on students. Teachers do not give sufficient importance to teaching SSI as part of science education, it is not assumed or integrated. The feeling of being more aligned with their beliefs about how science should be taught nowadays, at most, gets teachers to make space for SSI-based instruction. Teachers propose isolated teaching of SSI, which takes place very seldomly and not necessarily connected to the rest of the yearly programme. Teachers include SSI as something special that will catch the attention of students mostly because it is different than what they are used to. This is a common threat to the sustainability of an educational innovation, seeing that when the novelty effect has faded out, teachers may stop using it.

1.3.4. Factors of resistance from the context

As an innovative educational practice, if SSI-based instruction aims to be performed extensively and systematically, it must fit into the characteristics and the needs of secondary school science instruction. According to teachers, secondary school is not prepared for SSI-based instruction. There is pressure to cover a very dense curriculum that makes it stressful to address SSI. Furthermore, there is a need to collect student learning evidences, which is difficult to do for SSI where argumentation is key, thus it is hard to check to what extent students are right or wrong in their understanding of the SSI. Moreover, SSI need time, whereas the school organisation by a weekly schedule makes teachers to have only one hour with their students, and if they want more they must take time from other lessons they teach or coordinate with other teachers. Additionally, the size of the group-class, according to the results of this research, is too big to be able to scaffold individual student learning about the SSI.
Seeing these difficulties, possibilities were found to successfully deliver SSI-based instruction. If the time is short, teachers and students with experience in innovative methodologies will be more likely to apply SSI-based instruction than those who don’t, as it was shown in this research that teachers with little experience and especially with students who are not used to doing these activities require more time. This means that there is still space for SSI-based instruction in this educational context, but as an educational innovation it will mostly be performed by teachers who already have experience in innovative, student-centered or discussion-based teaching methodologies. Thus, targeting these teachers would be a valid strategy to support SSI-based instruction in this educational context.

1.4. Main research question (RQ): How do secondary school science teachers deliver SSI-based instruction, as a way to innovate in their practice?

In order to respond to the main research question, and based on the answers to the three sub-questions, a few assertions can be made. Teachers agree with the reasons to introduce SSI-based instruction as a way to help students develop scientific competence for responsible, conscious and active citizenship. The main reasons they give are: SSI as real-world problems worth for students to know as part of their science studies; SSI conveys the lack of black and white answers in science, and the need for argumentation; SSI is useful to develop skills to interpret and make sense of the scientific information that is disseminated in the information society; SSI conveys the need for citizens to take action and make decisions about issues that affect their life.

Teachers use SSI-based instruction to teach certain aspects of scientific knowledge, as they are determined in international assessment tests and national curricula. In terms of scientific knowledge, it was confirmed that the most common for teachers is to use SSI-based instruction to convey content knowledge, this is, scientific facts and principles. The strongest links found were between SSI and content knowledge related to health and environment. However, it was found that SSI also helps teachers to develop students' procedural and epistemic knowledge. The key procedural knowledge that SSI-based instruction is useful for is that argumentation is needed to justify scientific claims. The arguments and justification of SSI claims that teachers use are political, economic, or even ethical, but as science teachers, they emphasize scientific arguments. In terms of epistemic knowledge, their view corresponds to what has been described as the consequentialist approach to the relation
between science and society, which focuses on avoiding the undesirable effects of science in society, rather than current approaches such as RRI, where science and society are part of the same system.

Teachers are familiar with and have experience facilitating discussions about SSI in class. However, they use them as an introduction student learning activity or to close the lesson. This indicates that they do not have experience in using SSI in a structured manner, where the SSI is transversal to the teaching and learning activity. Still, evidence was found supporting that SSI-based instruction can be delivered as part of an innovation in science lessons. Most aspects of the IBL methodological approach are familiar to science teachers. For example, they see it as a process made of 3 phases. However, other aspects are less clear. In particular, teachers have a limited understanding of phase 3) Evaluate. Instead of focusing on students making a reflective conclusion and communicate the results of the process of inquiry, they see it as the moment to assess student learning. This means that in practice, SSI-based instruction is delivered as a shorter learning sequence than it's thought to be, and that without phase 3) Evaluate, student learning about the SSI may be incomplete. However, teachers do not have a systematic approach to assess student learning in SSI-based instruction.

Furthermore, in teachers’ opinion, dilemmas and group discussion, as techniques to discuss SSI in class, hold a lot of potential to the extent that they allow students to express their starting knowledge about the SSI, learn to express other points of view that are not their own, or listen to other points of view. Especially for group discussion, teachers invest most of the time and effort in the formal aspects of these techniques to engage students, such as setting the rules for the discussion, making sure the discussion is focused on the topic, among others. All of this suggests that teachers are more concerned and focused about the formal aspects of dilemmas and discussions, rather than their content.

Teachers are likely to deliver SSI-based instruction more or less frequently according to a few factors. One factor is teachers’ perceptions of how ready their students are. Another factor is their self-perceived level of competences in SSI-based instruction: teachers who are confident about their own skills will do it more often than those who don’t, especially their skills to manage discussion about SSI.

A tension was identified between the potential of SSI-based instruction to improve science learning processes and results and teachers’ self-perception that neither them or their
students are sufficiently skilled for that. Teachers with low confidence do not take risks when delivering SSI-based instruction: they hold on to the topic they know, and they have low expectations of the activity, especially in terms of student learning. Instead, they focus on engaging students and doing something "fun". Some teachers' main argument is that SSI-based instruction is worthwhile because it is very different to how they usually teach science. The conclusion that can be drawn is that when the novelty effect has vanished, SSI-based instruction will face similar challenges as non-SSI based instruction. Another practical implications of this conclusion is that SSI-based instruction is an educational innovation that is more likely to succeed or be implemented in educational contexts that already have some experience with innovative science teaching methods, especially those focussed on personally involving students in a scientific problem to solve.

Another factor affecting how often teachers use SSI-based instruction is the resistances they perceive from outside the classroom: if the time allocated for a lesson is too short, SSI-based instruction will be applied in a more shallow way. If they think the curriculum is too dense, they will find it harder to make time for it. For this reason, for most teachers SSI-based instruction is a one-of-a-kind, isolated learning activity that takes place outside their usual teaching, as opposed to a frequent activity. It enables them to motivate students towards learning, it has an utilitarian purpose in this sense.

In other words, the present study provides evidence that SSI-based instruction exists in teaching practice, as it has been showed in studies from other countries with similar, science and technology driven societies. However, it is not very structured. SSI may not have been sufficiently incorporated or supported yet in educational policy or in the curriculum.

Some key aspects for the success of SSI-based instruction, according to teachers, are to what extent the SSI is interesting for students, and to what extent the learning activities maintain students' interest and engaged throughout the lesson. These are not aspects that science teachers usually take into account when teaching other contents. Teachers need new skills that they can develop through PST or IST education if they want to teach SSI: some of them are "disciplinary" (how to look for reliable sources of information), others are pedagogical (how to manage a discussion). Their competences in delivering SSI-based instruction are low, they have good intentions but low competences.
2. Limitations of this research

As the research process is completed and the conclusions obtained, it is necessary to identify the challenges that this study faced. These are expressed as follows, so that future research on the same topic can take them into account.

There was a high level of diversity in terms of the level of detail that the participants provided in the data collection sources. This can be considered a strength as it allowed to approach the reality being studied without much intervention. However, the differences in quality and quantity of data that teachers provided made it difficult to identify clear trends, thus constituting a challenge to the goal to provide a deep understanding of the phenomenon of SSI-based instruction. On the other hand, the multiple case study design where tendencies were identified in case 1 and then further information obtained and elaborated in case 2, facilitated this task.

Especially in case 1, some of the data collection sources were public for all the participants, meaning for example where teachers were sending their responses in an online forum where other teachers already had introduced their responses. This system is thought to encourage teacher participation, because they see that others have responded or it is easier for them to provide the data by building on the previous responses or disagreeing with them. Therefore, it is a way to ensure collecting sufficient and rich data from teachers. However, seeing the answers from others may have influenced teachers' responses. The fact that all the data was collected in an online way could have influenced teachers' responses, and less "natural" or spontaneous responses, compared to face-to-face. Where this limitation has been observed in this study, an effort was made to represent also the views from less vocal teachers, not just the predominant ones.

Another challenge has to do with using SSI materials as a way to elicit SSI-based instruction. Different materials covered different SSI, thus constituting a collection of materials that is diverse and represents the issues that are important at the moment of carrying out this research. However, this diversity made it difficult to compare and find trends about SSI-based instruction, especially for teachers who referred to specific materials dealing with a specific SSI. The diversity of SSI, though, was useful to collect useful data about the phenomenon under study, especially in dimension D2) Components of SSI-based instruction, because all SSI materials followed the same pedagogical approach, thus allowing to gather meaningful and reliable data from teachers. In contrast, in the analysis of other
dimensions such as for example D1) Objectives of SSI-based instruction and in particular certain categories such as scientific content, challenges appeared that made it challenging to establish well-grounded assertions.

In addition, this study faced some challenges at a conceptual level. The main one has to do with the definition of the object of this research, i.e. SSI-based instruction. As a construct, its very existence as a type of instruction has been questioned, arguing that it is just another instance of STS/E or other approaches. Publications that justify it, or position papers, are still being published. This challenge was overcome by clarifying the specific framework of SSI-based instruction as a teaching practice, which is introduced in science instruction as a way for students to have a science learning experience that is more consistent with the current conceptions of active, conscious and responsible citizenship.

Another challenge at a conceptual level was how to approach the phenomenon of SSI-based instruction as an educational innovation. Several frameworks are available to study educational innovations, as showed in Chapter 2: Theoretical framework. In this study, a multi-dimensional approach was chosen that allows to provide a comprehensive view of the phenomenon. Studying SSI-based instruction from the point of view of its objectives, its components, and the resistances it faces may seem shallow or lacking depth. However, it was considered necessary given that the available studies about the same phenomenon are granular, focussing only in one of the dimensions, whereas the concerns and the open questions about how to support and maintain SSI-based instruction are wider.

Last, it is worth mentioning the open discussion about how to compare and create knowledge about research with teachers from different science subjects. At a first look, research on SSI in formal education is usually constrained to a discipline: physics, chemistry, natural sciences, etc. This seems to be a common practice under the assumption that secondary school teaching practice is subject-specific. In lower levels such as primary education, instruction is more generalist, to the extent that it is delivered similarly across the different subjects. On the contrary, instruction in secondary, non-tertiary education is tied to a specific discipline: science, mathematics, language, etc. This division is also present in initial and in-service secondary school teacher education and teaching competence frameworks. However, a few arguments challenge this statement in the specific case of SSI-based instruction. The research about SSI in students could be subject specific, of interest for example in how to use SSI to teach a certain discipline or even a specific content or curriculum item. However, teachers are often assigned to a teaching profile and they have to teach different subjects to different
groups of students. Moreover, in the last years, most secondary school educational systems are shifting to a competence-based approach, which aims to bridge the boundaries between the traditional disciplines. After thoroughly reviewing these positions, this research follows the line of studies that do not distinguish teachers by discipline, as long as they teach experimental sciences in secondary level.
3. Implications of this research

Beyond the theoretical implications of this study for educational research, which have been detailed earlier in this chapter, the present study holds key value in educational practice. One of these implications is that by eliciting how teachers deliver SSI-based instruction based on empirical data, current or future instances of this phenomenon can be analysed in a systematic way following the three dimensional framework of analysis proposed. The analysis could help teachers themselves to critically evaluate how they deliver SSI-based instruction, and improve their practice. Furthermore, the conclusions obtained in this research could be of use for school management and science department heads in schools where SSI-based instruction is being delivered, to monitor and improve it if needed. Educational practitioners in other educational levels such as primary school could also benefit from the results of this investigation, seeing that SSI are starting to be taught in these educational levels. Similarly, science outreach events facilitators, who work in other educational contexts such as non-formal education could make use of this framework of analysis as long as they are practising SSI-based instruction.

There are also reasons to believe that SSI are being taught in secondary school more frequently. As opposed to a trend, this practice is consolidating in the field of formal education. A current example is the current Covid-19 pandemic situation, which constitutes an SSI that has been addressed in formal secondary education due to the impact and meaning that has for students' lives. The findings about how teachers deliver SSI-based instruction were already important, but have become even more necessary in the pandemic context.

At the same time, the findings are relevant for educational interventions based on SSI. These interventions promote in-service teachers' use of SSI-based instruction in practice as a way to help them develop knowledge that will improve their practice, for example pedagogical. The knowledge developed in this research may help to better interpret the impact of these interventions in teachers.

Beyond these implications, the study may be of interest to curriculum developers. Teachers' interest in the curriculum content confirms the need to review or change the science curriculum as a way to facilitate, promote and deepen SSI-based instruction, where including SSI in the curriculum could facilitate that teachers address them in class. In this sense, teachers could be considered experts who have both a disciplinary and a pedagogical training and experience, which could be valuable to determine what competences, knowledge or skills
students should have. However, choosing which SSI to include in the curriculum can be controversial, especially for those SSI whose impact in our lives decreases or involves ethical or ideological arguments. Moreover, which contents to remove from the curriculum and which new ones to add, is a debate that requires the participation of experts, practitioners, and policy makers, as well as considering other societal goals such as the need to promote scientific careers. This goal calls for preparation of "future scientists" that have strong knowledge and skill foundations to follow science or STEM-related higher education degrees. This makes it necessary to maintain a strong disciplinary approach in secondary school as a university preparation educational level.

Another community beyond educational research where this study could be useful is initial science teacher education, especially their pedagogical training. Some teacher educators are addressing SSI and SSI-based instruction in initial teacher training, but not in a systematic way. The knowledge developed in this investigation about how teachers deliver SSI-based instruction could be used to update training programmes and compensate for the aspects where teacher educators could deliver it with more potential. Further, SSI-based instruction could become part of the curriculum of initial teacher training. This outcome would be a success of educational research, as it has occurred before with STS/E education, which arose in educational research and materialised in educational policy and legislation.

Last, developers of curricular materials and publishing houses may profit from the findings of the present study. The trends identified in SSI-based instruction may serve to design and publish SSI materials that suit teachers' needs. All these actions directed to teachers will affect positively students as well, because of the important role that teachers have in students' actual learning experiences at school.
4. Future research

The results of this study, while making a contribution to the state of the art of SSI-based instruction, confirmed the need to keep researching about this topic. In spite of the limitations that have been mentioned in section above, it is expected that this study sets the foundations for future research, which overcomes the difficulties encountered and addresses new research problems. The main lines of research that could be followed are presented in this section.

Some lines of action could be followed on the basis of the conclusions obtained regarding to what extent teachers share the view of SSI-based instruction as a way to help students develop a conscious, responsible and active citizenship in science education. This research revealed that teachers are particularly interested about certain SSI such as those related to health and the environment. Research that focusses on how different teachers teach the same SSI, what teachers know about it, how they present it to students and how they scaffold student learning would enable to identify tendencies that are useful to predict, maintain and expand SSI-based instruction of the SSI that are taught more frequently.

Other lines of research appear related to the question of how teachers deliver SSI-based instruction as part of a lesson. Deeper understanding could be achieved about the contributions of IBL to SSI-based instruction, especially regarding the tension between teachers' will that all students reach similar learning objectives while taking the most of IBL as a student-led learning process. Furthermore, the need for systematic ways to assess student learning during SSI-based instruction arose from teachers. From the field of didactics of science, this need could be met by research that designs, validates and tests assessment frameworks that cater for the diversity of students that can be found in average secondary school classrooms.

Finally, some of the opportunities and challenges that SSI-based instruction faces in secondary school science education are worth understanding more deeply. First, evidences were found that SSI-based instruction is an opportunity to teach about the epistemic aspects of science, which means that SSI-based instruction is delivered with a purpose that goes beyond teaching scientific content in context. This aspect could not be sufficiently investigated in this research, whereas the epistemic aspects of science are gaining importance in secondary school science curricula. Second, a relation emerged between teachers' knowledge about SSI-based instruction, their will to deliver it, and the obstacles they perceive.
from the school organisation. An intra-participant analysis could be useful to find trends in the relations between these factors that emerged as obstacles to teachers' delivery of SSI-based instruction when it is used as an educational innovation. More specifically, regarding teachers' skills to deliver SSI-based instruction, it would be worth researching the process by which teachers become experts.
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## 1. Appendix 1: Engage materials

### 1.1. List of Engage materials

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Take the test?</td>
<td>In this lesson the students are presented with an intriguing dilemma about whether a boy should have a screening test after his fiancée has found out she is a carrier of sickle cell disease. Students use information presented by experts to weigh up the options and come to a reasoned decision.</td>
</tr>
<tr>
<td>2</td>
<td>Attack of the giant viruses</td>
<td>Scientists have discovered a giant 30 000 year old virus still alive under the permafrost. As the world warms, others will be uncovered. Could such an ancient virus wipe out the human race?</td>
</tr>
<tr>
<td>3</td>
<td>Ban the beds</td>
<td>In this activity students are working as researchers on a TV show planning a report about the claim that sunbeds cause skin cancer. Students will use knowledge about UV light to explain the link between sunbeds and skin cancer, and understand how scientific evidence can support a claim.</td>
</tr>
<tr>
<td>4</td>
<td>Sinking island</td>
<td>The Pacific island nation of Kiribati recently announced its purchase of land for its population to move to when sea level rises make life on its own low-lying islands impossible. In this activity students use data to predict sea level rises. If humans are to blame for climate change, should the biggest polluters pay for land for vulnerable islanders to escape to?</td>
</tr>
<tr>
<td>5</td>
<td>Car Wars</td>
<td>Increased carbon dioxide emissions have led to huge financial incentives to buy alternatives to petrol engines – but which car is best?</td>
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<tr>
<td>6</td>
<td>Solar Roadways</td>
<td>Revolutionary roads which stay snow-free. A click of a switch they can transform the road into a car park. In this activity students consider whether solar roadways are worth funding. They critique claims and apply what they know about generating electricity in solar cells, to make a decision.</td>
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<tr>
<td>7</td>
<td>Eat insects</td>
<td>Farming large animals puts a strain on our natural resources and creates polluting waste. Scientists are proposing eating insects to help solve this problem. In this activity students are asked to plan a</td>
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<tr>
<td>8</td>
<td>Appliance science</td>
<td>The EU has recently imposed limits on the power ratings of vacuum cleaners, and further limits are expected. In this activity students consider a further (fictional) future restriction, on home electricity use. They are set the challenge of deciding how to cut their personal electricity consumption.</td>
</tr>
<tr>
<td>9</td>
<td>Making Decisions</td>
<td>In this activity students are placed in the role of a couple who are carriers of beta thalassaemia major. They are guided through how to make a difficult ethical decision and are introduced to IVF and the technology of pre-implantation genetic diagnosis.</td>
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<tr>
<td>10</td>
<td>Chocolate money</td>
<td>Europeans are eating more cocoa than can be produced. In this activity students apply their knowledge of pollination to discuss why cocoa yields on a plantation are decreasing. They then find out who funds scientific research by taking roles in a funding meeting – can they work out a deal where all parties will benefit?</td>
</tr>
<tr>
<td>11</td>
<td>Big Bag Ban</td>
<td>In this activity students examine degradable plastic bags as a possible alternative to ordinary plastic bags. They choose questions to ask experts, and come to a reasoned decision in answer to the dilemma question: will degradable plastic bags solve the problems caused by ordinary plastic bags?</td>
</tr>
<tr>
<td>12</td>
<td>Genetically Modified (GMO) decision</td>
<td>Following a EU rule change, the growing of GM crops across Europe will increase in many countries. In this activity students apply their knowledge about genes to learn why crops are genetically modified before evaluating health risks to decide which cereal they would buy.</td>
</tr>
<tr>
<td>13</td>
<td>What does the fox say?</td>
<td>We use the viral video to raise a serious question: can we understand animal talk? ‘Bowlingual’ detects a dog’s emotions by analysing a bark’s sound waves. Students look at emerging research to decide what else the technology can do. Can we translate the sound waves into human speech?</td>
</tr>
<tr>
<td>14</td>
<td>Text Neck</td>
<td>New research suggests that smart phone use is damaging our necks. In this activity students devise a plan to investigate the causes of text</td>
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<tr>
<td>neck, before solving a dilemma: will they use their phone less to prevent neck damage?</td>
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<tr>
<td><strong>15</strong></td>
<td><strong>Ebola</strong></td>
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<tr>
<td>The 2014 Ebola outbreak in West Africa was the largest in history. Scientists have responded quickly with a number of possible vaccines. In this activity students are asked if they would volunteer to be part of the safety trial.</td>
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<tr>
<td><strong>16</strong></td>
<td><strong>Invasion!</strong></td>
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<tr>
<td>Common ragweed, Ambrosia artemisiifolia, is an invasive plant which is spreading across Europe costing an estimated €4.5 billion a year. In this activity students evaluate the advantages and disadvantages of using biological control to halt the invasion of this alien plant.</td>
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<tr>
<td><strong>17</strong></td>
<td><strong>Life on Enceladus?</strong></td>
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<tr>
<td>In this activity students use their knowledge of the behaviour of water to weigh up the evidence for and against the presence of liquid water on Enceladus. They then decide if it is worth sending a second spacecraft to look for alien life on this icy moon.</td>
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<tr>
<td><strong>18</strong></td>
<td><strong>Animal testing</strong></td>
<td></td>
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<tr>
<td>1.2 million EU citizens have signed a petition for the complete ban of animal testing. In this activity students apply their knowledge about how asthma affects the gas exchange system to decide if animal testing is essential to developing new asthma drugs.</td>
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<tr>
<td><strong>19</strong></td>
<td><strong>Electronic cigarettes</strong></td>
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<tr>
<td>In this activity students decide whether they support a ban of using electronic cigarettes indoors. They apply their knowledge of particle theory to decide whether exhaled nicotine can reach non-vapers nearby, and learn to judge risks to decide whether the benefits of a ban outweigh the risks.</td>
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<tr>
<td><strong>20</strong></td>
<td><strong>Death to Diesel?</strong></td>
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<tr>
<td>In this activity students use their knowledge of chemical reactions to predict the products of combustion in a diesel engine. They then draft a video to persuade car buyers not to buy diesel cars.</td>
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<tr>
<td><strong>21</strong></td>
<td><strong>Zika</strong></td>
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<tr>
<td>The World Health Organisation declared the Zika virus an international emergency. Scientists are working on a vaccine and will soon want to test it on people. The Dilemma for students is: would you test a Zika vaccine?</td>
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<td><strong>22</strong></td>
<td><strong>Grow your own body</strong></td>
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<tr>
<td>As people live longer the demand for new organs to replace failed ones increases. One possible solution is to build new organs in a dish from cells taken from the patient’s own body. Students use</td>
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<tr>
<td>23</td>
<td>Ban Cola?</td>
<td>Now that scientists have discovered that sugar is like an addictive drug, pressure is building for action. In this activity, students consider the evidence for causal links between sugar consumption, obesity and disease. They then weigh up arguments for and against banning sugary drink sales to under-18s.</td>
</tr>
<tr>
<td>24</td>
<td>Man or Machine</td>
<td>Sports records are continually being broken, but are these improvements down to the athlete or the engineering? In this activity students apply their knowledge of frictional forces to design a racing bicycle to help a team smash more records on the cycling track in the Olympic Games.</td>
</tr>
<tr>
<td>25</td>
<td>Two Degrees</td>
<td>In this sequence students apply their knowledge about Climate Change to create an apocalyptic weather report. Then they judge solutions for limiting the temperature rise to 2 degrees.</td>
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<tr>
<td>26</td>
<td>To frack or not?</td>
<td>Whilst some countries in Europe have banned fracking, others want to exploit shale gas reserves to provide new – and cheap – sources of natural gas. In this activity, students decide whether they support a ban on fracking by applying their knowledge of the properties of rocks.</td>
</tr>
<tr>
<td>27</td>
<td>Exterminate</td>
<td>Mosquitoes are the world’s most dangerous killer. The diseases they transmit, malaria, Zika and dengue fever, cause more than a million deaths per year. In this project, students investigate whether exterminating mosquitoes is a good idea.</td>
</tr>
<tr>
<td>28</td>
<td>3 parents</td>
<td>The first baby with DNA from three parents has just been born in Mexico. Scientists spliced the egg of a third donor parent together with the mother’s mitochondria and fertilised it with the father’s sperm. In this activity, students learn how it can help women with a serious inherited condition to have a healthy baby and why it is deemed so controversial.</td>
</tr>
<tr>
<td>29</td>
<td>Eco-phone</td>
<td>As the number of smartphone users worldwide exceeds 2 billion, and as users update their devices with ever-increasing frequency, there are growing concerns about the impacts of smartphone manufacture and disposal on the environment and human health. In</td>
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<td>Vitamin D</td>
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<tr>
<td>30</td>
<td>Using the principles of ‘science capital’, this activity makes the issue of Vitamin D deficiency highly accessible and relevant to students’ everyday experience. Some scientists are recommending teenagers take vitamin D supplements, particularly in autumn and winter. The activity teaches students how to analyse patterns in data, so they can calculate their vitamin D intake from food and the sun and come to an informed decision.</td>
<td></td>
</tr>
</tbody>
</table>
1.2. Example of a material: Appliance Science

Teacher guide

OVERVIEW
The EU has recently imposed limits on the power ratings of vacuum cleaners, and proposes further limits on appliances such as hairdryers. In this activity students consider a further (fictional) future restriction, on home electricity use. Students calculate the energy transferred daily by the appliances they use. They then decide how to cut their electricity consumption so as to meet strict new legal limits.

LEARNING OBJECTIVE
In this lesson students will analyse a science issue using:

- Energy: the power ratings of electrical appliances and the energy they transfer
- Science in society: define a problem and work out how to solve it

CURRICULUM LINK
Common contents of Natural Sciences (2nd of ESO):

- Familiarization with the basic characteristics of scientific work through: posing problems, discussing their interest, formulating conjectures, etc. To better understand natural phenomena and solve the problems that their study raises.

- Recognition of the role of scientific knowledge in technological development and in people's lives

Specific contents:

- Preparation of proposals for individual and collective measures, energy saving, in the immediate environment

Note: Although it is possible that the concept of power has not been worked on, in the material the Kwh is used as a measure of energy. Therefore, the activity will not present difficulties to students of that course in terms of calculations or units.

This material can also be used in other subjects at the teacher’s choice

TEACHING MATERIALS
- The presentation PowerPoint contains both the teaching presentation and the Student Sheets.
- ENGAGE materials are published by the ENGAGE project from the European Commission, as Open Educational Resources, and are published under the Creative Commons NoDerivatives, NonCommercial license. They can be freely used, but not re-published in any revised form.
- Visit the ENGAGE website www.engagingscience.eu/es for more science-in-the-news activities.

Note: The materials are presented in English in this document, but the participants in this research accessed versions in Spanish.
<table>
<thead>
<tr>
<th>STAGE/PURPOSE</th>
<th>RUNNING NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dilemma</strong></td>
<td>The EU has imposed limits on home electricity use. Can students make big enough cuts? Display (2) and point out that the EU has already imposed limits on the power ratings of electrical appliances. Ask students to suggest why. Elicit that the purpose is to cut electricity use and greenhouse gases. Then introduce the (fictional) future limit on home electricity use. What do students think of this restriction? How can they reduce their own use of electricity?</td>
</tr>
<tr>
<td><strong>Science</strong></td>
<td>Students identify appliances with high power ratings, and rank appliances according to their power ratings. They calculate energy transferred by electrical appliances. Display (4) and ask students to identify the three appliances with the highest power ratings. The answer is those that transfer the most heat – the hairdryer, shower and iron. Distribute copies of cards cut from SS1a and SS1b so that each group has 8 cards. Students convert all power ratings to kW (they could use whiteboard pens to write these on the cards) and order the cards from the highest power rating to the lowest. You may want to discuss beforehand with the class how to convert W to kW and vice versa. Display (5) and go through the worked example. Students make up similar questions for their peers, using the power rating values given on the cards.</td>
</tr>
<tr>
<td><strong>Decision</strong></td>
<td>Students show the energy transferred by the appliances they use in a typical day and decide how to cut their appliance use so as not to exceed their daily personal electricity allowance of 1.5 kWh. Display (6) to outline the task – to work out how to cut appliance use so as not to exceed a daily maximum of 1.5 kWh. <strong>Either</strong> Students work through SS2 to calculate the energy transferred by the appliances they use in a typical day. They use SS3a and SS3b to represent this visually. They then continue to follow the instructions on SS3a to decide how to cut their appliance use so as not to exceed their daily personal electricity allowance of 1.5 kWh. <strong>Or do the calculation-free version:</strong> Students follow the instructions on SS4a to show the energy transferred by the appliances they use in a typical day. They then continue to follow the instructions to decide how to cut their appliance use so as not to exceed their daily personal electricity allowance of 1.5 kWh.</td>
</tr>
<tr>
<td><strong>Plenary</strong></td>
<td>Students reflect on the decision. Consider the questions (7). Students might suggest using more efficient appliances, or installing solar panels, to get more time for their allowance. They might point out that their heating needs change according to the season.</td>
</tr>
</tbody>
</table>
Presentation for the teacher

In this dilemma, you will analyse a science issue using:

**Energy:** the power ratings of electrical appliances and the energy they transfer

**Science in society:** define a problem and work out how to solve it

**Dilemma**

**Science**

**Decision**

---

**How much energy do appliances transfer?**

energy transferred = power x time

kWh = kW x h

Q: If you are in an 8 kW shower for ¼ hour, how much energy is transferred?

A: Energy transferred = 8kW x ¼ hour = 2 kWh

---

**How can you get more time for your allowance?**

What might make you change how you use your allowance?
### Student sheets

#### Appliance science

<table>
<thead>
<tr>
<th>Sheet no.</th>
<th>Title</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>S1a and Sb</td>
<td>Appliance cards</td>
<td>Reusable, cut-up and laminate, one set of 8 cards for each group</td>
</tr>
<tr>
<td>S2</td>
<td>Electricity use table</td>
<td>Consists of, one for each student (but students who are doing the calculation free version of this activity do not need this sheet)</td>
</tr>
<tr>
<td>S3a and Sb</td>
<td>Appliance energy strips</td>
<td>Consists of, print in colour if possible, one for each student who is doing the calculations on S2</td>
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<tr>
<td>S4a and Sb</td>
<td>Appliance energy strips (calculation sheet)</td>
<td>Consists of, print in colour if possible, one per student who is doing the calculations on S2</td>
</tr>
</tbody>
</table>

For more, visit EngagingScience.eu

#### Appliance cards

- **Electric heater**
  - Power rating = 2 kW

- **Wi-Fi router**
  - Power rating = 6 W

- **Game console**
  - Power rating = 200 W

- **Mobile phone charger**
  - Power rating = 3 W

#### Electricity use table

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Power (W)</th>
<th>Time (h)</th>
<th>Energy transferred (kWh)</th>
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<tbody>
<tr>
<td>Shower</td>
<td>5</td>
<td>0.08</td>
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<tr>
<td>Hairdryer</td>
<td>2</td>
<td>0.17</td>
<td></td>
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<tr>
<td>Heater</td>
<td>0.3</td>
<td>0.53</td>
<td></td>
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<tr>
<td>Game console</td>
<td>0.2</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Desktop computer</td>
<td>0.006</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>Mobile phone charger</td>
<td>0.003</td>
<td></td>
<td></td>
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</tbody>
</table>

Conversion table

#### Appliance energy strips

<table>
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<tr>
<th>Appliance</th>
<th>Power (kW)</th>
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<tbody>
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<td>1.6</td>
</tr>
<tr>
<td>Hairdryer</td>
<td>0.64</td>
</tr>
<tr>
<td>Heater</td>
<td>1.0</td>
</tr>
<tr>
<td>Game console</td>
<td>0.3</td>
</tr>
<tr>
<td>Desktop computer</td>
<td>0.64</td>
</tr>
<tr>
<td>Wi-Fi router</td>
<td>0.7</td>
</tr>
<tr>
<td>Mobile phone charger</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Grey Strip A
- The electricity you use now (go beyond this strip if you need to)

Grey Strip B
- Your electricity allowance of 1.6 kWh (do not go beyond this strip)
1.3. Example of a material: Ban Cola
Teacher guide

OVERVIEW
Now that scientists have discovered that sugar is like an addictive drug, pressure is building for action to reduce the amount of sugar that children and young people consume in sugary drinks. In this activity, students consider the evidence for causal links between sugar consumption, obesity and disease. They then weigh up arguments for and against banning sugary drink sales to under-18s.

LEARNING OBJECTIVES
In this lesson students will:

• Apply knowledge about food and health
• Use evidence to decide whether a correlation is causal
• Evaluate and synthesise information to make a decision about a health-related issue

CURRICULUM LINK
Common contents of Natural Sciences (3rd of ESO):

• Familiarization with the basic characteristics of scientific work through: posing problems, discussing their interest, formulating conjectures, etc. To better understand natural phenomena and solve the problems that their study raises.

• Recognition of the role of scientific knowledge in technological development and in people’s lives

Specific contents (3rd of ESO):

• Block 5. People and health

This material can also be used in other subjects at the teacher’s choice

TEACHING MATERIALS

• The Presentation PowerPoint is the lesson backbone. The Student Sheets are separate, and are reusable or consumable and sharable as indicated.

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• Visit the ENGAGE website www.engagingscience.eu/es for weblinks relating to this activity.
<table>
<thead>
<tr>
<th>STAGE/PURPOSE</th>
<th>RUNNING NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starter</strong></td>
<td>Show the trailer to the film Fed Up <a href="http://www.imdb.com/title/tt2381335/">http://www.imdb.com/title/tt2381335/</a> as a sensationalised introduction to the activity. Display (3) to show the big question students will consider. Show a can or bottle of cola and display (4) to ask students to guess its sugar content. Get a student to measure out 10 teaspoonfuls or small packets of sugar, the amount in the can.</td>
</tr>
<tr>
<td><strong>Core task</strong></td>
<td>Remind students that if a person consumes more energy than they use they will put on weight. Display (5) and ask for students’ immediate reactions – did excess sugary drinks cause Jed’s obesity, or could there be another factor, such as a reduction in exercise? Point out that a link between two factors is only weak evidence for a claim. Ask students to suggest what might provide stronger evidence that sugar causes obesity. Provide evidence cards from SS1. Groups follow the instruction at the top of (6) to sort the cards. Groups make their decision, and share with the class, giving reasons.</td>
</tr>
<tr>
<td><strong>Plenary 1</strong></td>
<td>Use the first part of (7) to point out that it is not certain that excess sugary drink consumption causes obesity. There is uncertainty in any conclusion. Use the second part of (7) to make the point that scientists can be more confident in a conclusion if there is a plausible mechanism explaining the link between two variables, in this case the explanation that sugar acts like an addictive drug, at least to lab rats. At this stage students are likely to feel that there is not enough evidence to support a ban on sugary drink sales to under-18s.</td>
</tr>
<tr>
<td><strong>Extension</strong></td>
<td>Display (8). Student groups use cards from SS2 to address the big question – should we ban sugary drink sales to under-18s? Some groups share their decisions with the class, giving reasons.</td>
</tr>
</tbody>
</table>
Plenary 2
(5 min) The decision on the ban cannot be based on science alone.

Discuss how groups made their decisions. Elicit that the decision cannot be based on science alone. Other factors, such as ethics, must be considered.

Point out that, even though there is no scientific consensus, at some point it is reasonable to make a judgement and say that the possible consequences of an action (over-consumption of sugary drinks) are so bad that taking another action (banning sugary drink sales to under-18s) is justified.

Presentation for the teacher

(Continues in next page)
Jed drinks lots of sugary drinks. He becomes obese.

So do sugary drinks cause obesity?

Sort the evidence that sugar causes obesity:

- weak evidence
- strong evidence

Is there enough evidence to ban sugary drink sales to under-18s?

What's the conclusion?
It's uncertain. Not all scientists agree.

Will they ever agree?
Scientists will be more confident that sugary drinks cause obesity if they can explain how.

“We are considering a ban on fizzy drink sales to under-18s. What do you think?”

Weigh up the pros and cons. Do you support a ban?

Were all your reasons scientific?

What else did you think about when making your decision?
### Student sheets

#### Ban cola

<table>
<thead>
<tr>
<th>Sheet no.</th>
<th>Title</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>551</td>
<td>Evidence cards</td>
<td>Reusable, cut into cards, one per group</td>
</tr>
<tr>
<td>552</td>
<td>Argument cards</td>
<td>Reusable, cut into cards, one per group</td>
</tr>
</tbody>
</table>

For more, visit EngagingScience.eu

#### Evidence cards

- Unhealthy diets lead to obesity
- The World Health Organization recommends reducing sugar intake to less than 10% of daily energy intake
- Unhealthy diets are linked to a higher risk of heart disease
- After four weeks, the group that reduced sugar intake saw a significant decrease in weight

#### Argument cards

- We get 15 students to base their argument on evidence. The less detail was added, the more logical the argument. This is why we need evidence to support our claims.
- "I am not sure whether or not this idea will work. I mean, if it doesn’t work, then we can try something else."
- "We need to prove that this idea is effective."
- "I think we need more information about this idea."
- "I agree that this idea needs more research."
- "I think this idea is feasible."
- "I am not sure whether this idea will work."
- "We need to prove that this idea is effective."
- "I think we need more information about this idea."
- "I agree that this idea needs more research."
- "I think this idea is feasible."
- "I am not sure whether this idea will work."

*Source: Evidence Day, University of Oxford, UK*

### Student sheet
1.4. Example of a material: Text neck

Teacher guide

OVERVIEW

New research suggests that smart phone use is seriously damaging our necks. Looking down at an angle places great strain on the spine, and can result in serious harm. In this activity students learn about the forces acting on the spine. They then devise a plan to investigate the causes of text neck, before solving a dilemma: will they use their phone less to prevent neck damage?

LEARNING OBJECTIVE

In this lesson students make a decision about whether to use their phone less to prevent neck damage:

- Forces: identify forces on objects
- Science in society: define a problem and devise a plan to investigate it

CURRICULUM LINK

LOMCE blocks related to the activity:

Biology and Geology 3 ESO

- Use varied information sources, discriminate and decide on them and the methods used to obtain them. Physics and Chemistry 3 ESO
- Recognize the role of forces as a cause of changes in the state of motion and deformations.
- Develop small research projects in which the application of the scientific method and the use of ICT are put into practice.

Physics and Chemistry 4 ESO

- Recognize the role of forces as a cause of changes in the velocity of bodies and represent them vectorially.
- Check the need to use vectors to define certain quantities.

Physics and Chemistry (1 BACH)

- Identify all the forces that act on a body.
- Recognize and use the basic strategies of scientific activity such as: posing problems, formulating hypotheses, proposing models, developing problem-solving strategies and experimental designs and analysis of results.
### TEACHING MATERIALS

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### STAGE/PURPOSE | RUNNING NOTES
--- | ---
**Starter**
New research shows that using your phone may seriously damage your neck. Will you use your phone less to save your neck?  
Display (2) to show that using you phone to text, watch videos or use the internet may seriously damage your neck.  
Display (3) to illustrate the huge extra force on your spine when your head is bent. Ask students for their first thoughts on the dilemma question – will they use their phones less to save their necks?  
Display the objectives (4).

**Main**
Explain why the force on the top of your spine depends on neck angle. Plan how to investigate whether using your phone damages your neck.  
Display (5) to show the forces acting on the top of the neck in two positions. The force due to gravity is the same in each case, and acts vertically downwards. The force exerted by the neck muscles to keep the head in position is much greater with a bent neck – in the diagrams, the longer arrow represents the greater force. Students can feel this difference when they bend their heads. The resultant force acts on the top of the spine, and is shown by the *resultant force* arrows. These arrows shows the direction of the resultant force. Their relative lengths indicate the relative magnitudes. You can draw parallelograms to work out the size and direction of the resultant force.

![Diagram of forces](image)

Force due to gravity  
Force exerted by muscles to keep head in resultant force

Display (6) and ask groups to discuss the question. The force on the spine is greater in position A, since a greater force must be exerted by the muscles to keep the head in this position. The longer resultant force arrow shows this.

Display (7) to outline the main task. Give each group a set of cards cut from SS1 and copies of SS2a and SS2b.

You may wish to give each student SS3 to assess individual learning. Answers:
- Variables A, B, E, F, G and H might affect the outcome.
- Best ways of obtaining data: A – create an app; B – measure with inclination app or protractor and plumb line; E and F – journal data; G – graph; H – cannot measure in isolation. Students can consider how to ensure the data is as reliable as possible. If you wish, students can obtain data for variable B using a protractor and plumb line or an inclination app.
- Measure neck angle (B). Use the graph to find corresponding force on top of spine (G). Find out the amount of force on your spine that causes damage (F) and the time your neck can experience this force before damage is caused (E). Compare this time to the amount of time using phone (A).

**Plenary**

Students make a final decision on the dilemma question.

Display (8). Student groups use the information gathered to help them to solve the dilemma question.

**Presentation for the teacher**

(Continues in next page)
Bending your neck adds to the force exerted by your head on your spine.

At 60° the extra force is 220 N...

...about the weight of a 6-year-old.

Will you use your phone less to save your neck?

In this activity, you will

Make a decision about whether to use your phone less to prevent neck damage:

Forces: Identify forces on objects

Ask and Define: Define a problem and devise a plan to investigate it

The forces on your neck – 1

Force exerted by muscles to keep head in this position

Resultant force exerted by head on top of spine

Why does bending your neck add to the force on the bones at the top of your spine?

The forces on your neck – 2

Force exerted by muscles to keep head in this position

Resultant force exerted by head on top of spine

In which position is the force on the neck bigger?

Plan how to investigate this question:

- Choose variables that might affect the outcome.
- For each variable
  - identify at least one way of obtaining data.
  - then decide the best way of collecting reliable data for the variable.
- Work out how to use the data to decide if using your phone will damage your neck.

Will you use your phone less to save your neck? Why?

Student sheets
### 2. Appendix 2: Information about participants

The following tables provide background information about the participants of Case 1 and 2, respectively. The field "ID" is the unique identifier for the teacher, whereas "Age" indicates how old the participant is. "Gender" is female (F) or male (M), and "Years of experience" refers to how long they have been teaching in formal education. "Location" indicates the city and region or country where they work. The "Subject" field provides information about the subject they teach, which can be CCNN (Natural sciences), B (Biology), G (Geology), F (Physics) and / or Q (Chemistry). Finally, the field "School grade" describes the grade where they teach these subjects, which can be compulsory (ESO) or post-compulsory (BTX). When the information is available, a number indicates the year within this level that they teach. For example, 3ESO represents 3rd year of compulsory education, and 1BTX represents first year of post compulsory education. EEAA refers to adult education, which is equivalent to compulsory level, and CFGS refers to vocational training.

#### 2.1 Case 1

<table>
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3. Appendix 3: Data collection strategies

3.1. Open ended questionnaire

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<table>
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<tr>
<td>1. What do you think this course is about?</td>
</tr>
<tr>
<td>2. Does this course have anything to do with the curriculum you have to teach?</td>
</tr>
<tr>
<td>3. Can you identify any related element (objective, evaluation criteria, ...) in the curriculum of the subject (s) you teach?</td>
</tr>
<tr>
<td>4. Post your impressions, questions or reflections on the video about the Dilemma.</td>
</tr>
<tr>
<td>5. Propose a dilemma to tackle in class.</td>
</tr>
<tr>
<td>6. What's your opinion about the 3E model? Have you used it before? If so, how did your students react? What is the biggest challenge that you would have to apply this model in your classes?</td>
</tr>
<tr>
<td>7. How could we assess student learning in SSI-based instruction?</td>
</tr>
<tr>
<td>8. What are the benefits and challenges for you to have a discussion in small groups in the science classroom? How would you approach them? What is the role of the teacher?</td>
</tr>
<tr>
<td>9. Choose an Engage material and answer the following questions: Why do you think it is a good resource? What adaptations would you make to use it in your classes? What challenges would putting it into practice, and how would you solve them?</td>
</tr>
<tr>
<td>10. What are the benefits and challenges of holding a discussion in small groups in the science classroom? How would you approach them?</td>
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</table>
### 3.1.2. Case 2

**General information**

1. First and last name
2. Date of birth
3. The ENGAGE resource will be used in [Educational level]
4. What field do your most advanced completed studies belong to?
5. How long have you taught science?
6. Have you used any ENGAGE materials before? (You can check more than one option)
7. Name of the group-class
8. Age of the students
9. Date of the lesson
10. Topic of the lesson
11. ENGAGE resource that you will use in this lesson

**Items**

1. Personal objectives of the lesson
2. Why did you choose this Engage resource?
3. What do you want your students to learn?
4. Why is it important for students to learn it?
5. What difficulties (for the students) do you expect regarding the topic of this lesson?
6. What knowledge and skills are required of students to achieve the objectives of this lesson?
7. Do your students need to have any prior knowledge or beliefs outside of the topic of this Engage lesson?
8. What other factors can influence your teaching on this topic?
9. Will you use the approach suggested in the Engage material or will you make changes? Why? Explain your approach.
10. How will you make the Engage material relevant to your students? Do you plan to use any extra content or strategy to involve your students?
11. What would have to happen to be able to say that the lesson was successful?
3.2. Reflective diary

3.2.1. Case 1

1. What was, according to you, the "hook" that got the students involved?
2. Which challenges did you face?
3. To what extent do you think that the lesson was effective?
4. Were there any unexpected results?
5. What do you relate this experience with? Other innovations you have introduced in your lessons before
6. What changes could you do? Do you make any decision?

3.2.2. Case 2

1. How have you used the Engage material?
2. What learning objective(s) did you have in mind for the ENGAGE lessons?
3. Did you apply the ENGAGE material as you planned and prepared?
4. To what extent are you satisfied with the learning objectives you defined, and their relevance to students? Explain your answer.
5. Did you find that your students had any prior knowledge or beliefs about the lesson topic?
6. Regarding your students, what did they find easy and difficult in this ENGAGE lesson? How do you know?
7. Which [parts of the Engage material] worked and what didn't?
8. Were the students able to carry out the activities satisfactorily? Which activities were successful, and which were not?
9. To what extent are you satisfied with the way you have involved the students? Please explain.
10. To what extent do the activities in the lesson fit in with the learning objectives? Please explain.
11. To what extent do the activities fit with the group-class, the atmosphere in the classroom, the autonomy of the students, the diversity of the students, their development as a teacher and about the lesson? Please explain.
12. Have your students met the learning objectives? How do you know?
13. What would you change, next time, for your students to achieve the learning objectives?
14. Would you use this ENGAGE material again? If the answer is "Yes", would you do it differently? Please explain.
15. Would you recommend this ENGAGE material to other teachers? Why would you, or why wouldn't you?
16. Would you try another ENGAGE material, in the future? Why would you, or why wouldn't you?

**3.3 Teachers' outline of the lessons with the Engage materials**

After the lesson, teachers were asked to deliver an assignment in the PD covering the following points:

1. Which Engage material did you apply? If you created it, please indicate it.
2. Describe the outline of the lesson.
3. Did you organize a debate? How?
4. Which pedagogical strategies did you use throughout the lesson?

**3.4. Lesson observation**

The teachers provided video recordings of the lesson, which were analysed using the grid on the following page.
### PCK RELATED OBSERVATION FORM

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### NOTES SHEET

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4. Appendix 4: Ethical issues

4.1. Privacy policy of the site www.engagingscience.eu/es

1. Who is responsible for the processing of your data?

The person responsible for the processing of your personal data is the General Secretariat of the University of Barcelona, with the postal address Gran Via de les Corts Catalanes, 585, 08007 Barcelona and the email address secretaria.general@ub.edu.

2. For what purpose do we process your personal data?

The purpose of the treatment is to carry out the management of your registration as a user of the ENGAGE project website and allow you to download the materials it contains.

3. What is the legal basis for the processing of your data?

The legal basis for the processing of your personal data is your consent, which you can revoke at any time without having retroactive effects. The data collected is necessary to be able to carry out these treatments.

4. How long will we keep your personal data?

As long as they are necessary for the management of your status as a user of the ENGAGE project website and, at most, until April 1, 2020.

5. To which recipients will your data be provided?

To the university itself and to those in charge of the treatment, if applicable. The transfer of data to third parties is not contemplated, unless it is a legal obligation.

6. What are your rights?

You can access your data, request its rectification, deletion, portability or limitation of treatment, by writing to the General Secretary of the University of Barcelona (Gran Via de

9 Translated from Spanish
les Corts Catalanes, 585, 08007 Barcelona), or by an email message to the address secretaria.general@ub.edu. In any case, you will have to attach a photocopy of your ID or any other valid document that identifies you.

7. What are the contact details of the data protection officer?

If you consider that your rights have not been adequately addressed, you can notify the Delegate of Dades Protection of the UB by e-mail to the address protecciodedades@ub.edu or by writing to Travessera de les Corts, 131-159, Pavelló Rosa, 08028 Barcelona.

8. What avenues of claim do you have at your disposal?

You can also file a claim addressed to the Catalan Authority for Data Protection.
4.2. Information about the PD and its funding (case 1)

Socioscientific issues and inquiry for science teaching

**Description:**
The shift towards competency-based teaching is affecting experimental science and mathematics teaching. Today, science can no longer be taught as a static body of knowledge created by scientists. On the contrary, it is in constant evolution, influenced by economic, political or ethical factors on which citizens participate.

The course aims to improve science teaching by introducing Socioscientific Issues that help to understand phenomena from a responsible research and innovation perspective. We will introduce and experiment with useful strategies to teach scientific competence as we understand it today: inquiry, problem-based learning, debate, and scientific conversation. Teachers will have access to materials that help to apply these strategies in the classroom.

**Objectives:**
- Use Socioscientific Issues to involve students in learning, so that they think and talk scientifically
- Learn to organize group discussions that allow students to share and apply their knowledge to decision-making on relevant scientific topics
- Prepare students to participate in scientific conversations in which they use arguments based on evidence and reasoning
- Plan and design lessons based on problem solving through argumentation
- Plan, implement and reflect on the Engage materials

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10 Translated from Spanish
Contents:
- Socioscientific Issues for science teaching
- Dilemmas and Group Discussion for science teaching
- Problem-Based Learning for science teaching
- Scientific conversation for science teaching

Aimed at:
Secondary school science teachers (natural sciences, physics, chemistry, biology, geology, scientific culture ...). It may also be of interest to teachers of the last years of primary school and to others who are interested in the didactics of experimental sciences in relation to Responsible Research and Innovation.

Duration: 30 hours spread over 6 weeks (from 2/29 to 4/18)
Modality: Online
Assessment and certification: Based on peer assessment, the criteria are:
- Active participation in the online forums of the course
- Carrying out the proposed activities

Places: 150
Registration period: until 2/29
Price: free of charge

This course is funded with the help of the European Commission - Seventh Framework Program, European project ENGAGING SCIENCE (Equipping the next generation for active engagement in science).
4.3. Information about the research provided to participants (case 2)

INFORMATION ABOUT “PCK RESEARCH” (University of Barcelona)

Welcome to this research!
At the University of Barcelona we want to better understand the practice of science teachers. For this reason, we invite you to participate in an investigation in which you will be able to put into practice new teaching methods and contribute to the improvement of this field.

Teachers who meet the following requisites are invited:

- Willingness to carry out a lesson using at least one of the Engage materials based on Socioscientific Issues, available at engagingscience.eu/es
- Open attitude and willingness to reflect on science teaching
- Not having participated in any other activity of the Engaging Science project

We offer:

- Free, up-to-date Open Education Resources, designed by experts
- Didactic consultation
- Contact with other, innovative teachers
- A guide to reflect on your own teaching practice
- Possibility to obtain a certificate of participation in an European project
- Possibility to access the results of the research

The research will follow the procedure:

- Register at http://www.engagingscience.eu/es/ and download at least one of the following materials:
  - Ban Cola

Translated from Spanish
- Car wars
- Big bag ban
- Life on Enceladus?
- E-cigarettes
- Death to Diesel?

- Fill in the open-ended questionnaire
- **Carry out a lesson based on the material,** and record it in video (see section "Frequently Asked Questions"
- Send the video to silvia.alcaraz@ub.edu
- Fill in the reflective diary

**Frequently Asked Questions:**

What are the requisites for the videos?:

- At least 8 students must be visible
- It will only be used for the purposes of this study only and it will not be used for any other purpose

Can I fill in the forms by speaking, instead of writing?

Yes, you can answer both the open-ended questionnaire and the reflective diary through videocall, which can be arranged by sending an email to silvia.alcaraz@ub.edu

We are delighted to count on you, and we hope that this project helps you to engage your students in their learning, to reflect about your own practice, and to learn about new science teaching methods.

**More information:**

silvia.alcaraz@ub.edu | Facebook | Twitter | Project website
5. Appendix 5: Data analysis

5.1. List of documents in Atlas.ti

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<tr>
<td>2016_S3_AS_Implement&amp;reflect.pdf</td>
</tr>
<tr>
<td>2016_S4_FO_PlanImplementation1Material.doc</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1_LP.pdf</td>
</tr>
<tr>
<td>T1-OB.pdf</td>
</tr>
<tr>
<td>T1-LR.pdf</td>
</tr>
<tr>
<td>T2_LP.pdf</td>
</tr>
<tr>
<td>T2-OB.pdf</td>
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<tr>
<td>T2-LR.pdf</td>
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</tbody>
</table>
## 5.2. Code lists

*Initial code list:*

<table>
<thead>
<tr>
<th>Teacher ID</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>1T1, 1T2, 1T3, (...), 1T103, ... 2T1, 2T2, 2T3, ...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demographic data</th>
<th>Code</th>
</tr>
</thead>
</table>
| Age              | Age- 20-29  
|                  | Age- 30-39  
|                  | Age- 40-49  
|                  | Age- 50+    |

| Gender          | Gender- F  
|                | Gender- M  |

<table>
<thead>
<tr>
<th>Years of experience</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching experience- 1-2 years</td>
<td></td>
</tr>
<tr>
<td>Teaching experience- 3-5 years</td>
<td></td>
</tr>
<tr>
<td>Teaching experience- 6-10 years</td>
<td></td>
</tr>
<tr>
<td>Teaching experience- 11-15 years</td>
<td></td>
</tr>
<tr>
<td>Teaching experience- 16-20 years</td>
<td></td>
</tr>
<tr>
<td>Teaching experience- first year</td>
<td></td>
</tr>
<tr>
<td>Teaching experience- more than 20 years</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>School grade</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>School grade- 1ESO</td>
<td></td>
</tr>
<tr>
<td>School grade- 2ESO</td>
<td></td>
</tr>
<tr>
<td>Dimension, category, sub-category</td>
<td>Code</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Dimension 1: Objectives of SSI-based instruction</td>
<td>Dimension D1</td>
</tr>
<tr>
<td>Contribute to developing scientific literacy</td>
<td>Contribute to develop sci. lit.</td>
</tr>
<tr>
<td>- Explaining phenomena scientifically</td>
<td>Sci comp: Explain sci. phenomena</td>
</tr>
<tr>
<td>- Evaluating and designing scientific enquiry</td>
<td>Sci comp: Evaluate &amp; design sci. inquiry</td>
</tr>
<tr>
<td>- Interpreting data and evidence scientifically</td>
<td>Sci comp: Interpret sci. data and evidence</td>
</tr>
<tr>
<td>Teach scientific knowledge</td>
<td>Teach sci. knowledge</td>
</tr>
<tr>
<td>- Content knowledge</td>
<td>Knowledge: Content</td>
</tr>
<tr>
<td>- Procedural knowledge</td>
<td>Knowledge: Procedural</td>
</tr>
<tr>
<td>- Epistemic knowledge</td>
<td>Knowledge: Epistemic</td>
</tr>
<tr>
<td>Conveying the interdisciplinarity of knowledge</td>
<td>Conveying the interdisciplinarity of knowledge</td>
</tr>
<tr>
<td>Dimension 2: Components of SSI-based instruction</td>
<td>Dimension D2</td>
</tr>
<tr>
<td>Teaching methods</td>
<td>Teaching methods</td>
</tr>
<tr>
<td>- Inquiry-Based Learning</td>
<td>IBL</td>
</tr>
<tr>
<td>Techniques to discuss SSI</td>
<td>Techniques to discuss SSI</td>
</tr>
<tr>
<td>- Dilemmas</td>
<td>Techniques: dilemma</td>
</tr>
<tr>
<td>- Group discussion</td>
<td>Techniques: group discussion</td>
</tr>
<tr>
<td>Assessment of student learning</td>
<td>Assessment of student learning</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>• Dimension 3: Resistance to SSI-based instruction</td>
<td>Dimension D3</td>
</tr>
<tr>
<td>o Resistance on students</td>
<td>Students’ role</td>
</tr>
<tr>
<td>▪ Student participation</td>
<td>Unsuccessful reason: some students not engaged</td>
</tr>
<tr>
<td>▪ Personal implication in the SSI</td>
<td>Strengths: meaningful learning</td>
</tr>
<tr>
<td>o Resistance on content load</td>
<td>Content load</td>
</tr>
<tr>
<td>o Resistance on organisation, schedule, and timetable</td>
<td>Organisation, schedule, timetable</td>
</tr>
<tr>
<td>o Resistance on teachers’ choice of SSI</td>
<td>Success factors: appealing topic</td>
</tr>
</tbody>
</table>