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Transformation of School Science Practices to Promote Functional Scientific Literacy

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Abstract
The incorporation of socioscientific issues into science teaching to promote students' scientific literacy may require that science teachers reconsider and transform their teaching practices. This study examines the knowledge and considerations involved when two teachers incorporated socioscientific issues into their teaching, with the aim of understanding conditions for developing teaching to promote functional scientific literacy. Data consisted of written records of teaching, field notes of classroom observations and transcripts of meetings between the teachers and a researcher, generated during a year-long professional development project. Data were analysed through the framework of didactics that understands teaching as framed by societal conditions, curricula, teaching traditions and teacher and student knowledge and intentions. The results show that the incorporation of socioscientific issues enabled student engagement with scientific content, the practice of evidence-based reasoning and the consideration of values and norms. The teachers strove to seize upon student questions in teaching, and the results show that this may require strategies to raise questions among students, as well as profound science content knowledge on the part of teachers. Moreover, the results indicate that tensions arose between students' instrumental views of teaching and learning and the teachers' promotion of an exploratory classroom culture. The teachers had to support student adaption to the new requirements, and in this process, mutual trust and clear expectations were considered important. Implications for teachers' professional development in relation to the incorporation of socioscientific issues in science education are discussed.

Keywords Secondary school science · Scientific literacy · Socioscientific issues · Teacher reflection · Teaching practices

Introduction

An important aim of science education is students' development of knowledge, skills and intellectual attitudes useful for dealing with science-related issues that they encounter in daily life and for engaging in civic discourse about urgent socioscientific issues (SSI). This

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broad objective for science education, to contribute to laying "the groundwork for students to become functioning members of an informed democracy", has been referred to as functional scientific literacy (Zeidler & Sadler, 2011, p. 179). Several projects founded by the European Union during the last decades have focused on the promotion of scientific literacy through engagement with SSI (see, e.g. Amos & Levinson, 2019; Holbrook, 2008).

To foster functional scientific literacy, it is suggested that SSI be incorporated into science curricula, providing opportunities for students to explore both the knowledge and values at stake in the context of socially relevant issues by means of student-centred, discourse-based classroom practices (Zeidler, 2014). Therefore, the incorporation of SSI may challenge prevailing approaches to science teaching, where teachers are typically positioned as conveyors of content knowledge (Leden et al., 2020; Limbere et al., 2022; Lyons, 2006), and lead to teachers having to transform their teaching. There is a need to understand how teaching can be developed to foster scientific literacy and how teachers may be supported in this process (Chen & Xiao, 2021; Friedrichsen et al., 2021; Sadler et al., 2017). Through the framework of didactics, which facilitates reflection on the purpose, objectives, content and methods of teaching (Hudson, 2002; Uljens, 1997), this study explores the process by which two teachers incorporated SSI into their teaching. It aims to identify how they negotiated and transformed teaching practices for the promotion of functional scientific literacy.

Incorporation of SSI into Science Teaching—Objectives, Content and Methods

Aiming at fostering students' functional scientific literacy, teaching should ideally deal with pressing societal issues with connections to science that address personal, national and global dimensions and involve conflicting interests and ethical considerations (Ratcliffe & Grace, 2003; Zeidler, 2014). Research suggests that to be able to understand and negotiate SSI, students need some understanding of relevant science content. Even though some studies have suggested that students rarely apply science content knowledge explicitly in their reasoning (Christenson et al., 2012; Sadler & Donnelly, 2006), students may find it difficult to engage with SSI without understanding relevant science concepts (Lewis & Leach, 2006). Science content knowledge also seems to promote student understanding of contradictory interests or consequences of different courses of action (Ottander & Simon, 2021; Rudsberg & Öhman, 2015). On the other hand, research indicates that there is a risk that students, for instance, when faced with information circulating on the Internet, may privilege scientific perspectives on SSI and uncritically invoke in their reasoning scientific claims that are recontextualised by interest groups (Solli, 2021). Consequently, some understanding of the nature of scientific knowledge and the ways in which it is produced seems important for negotiating and making informed decisions on SSI (Khishfe, 2012).

Research suggests that certain dimensions are involved when students negotiate SSI. Students need to (1) recognise the complexity of SSI, (2) identify and search for missing information, (3) examine SSI from different stakeholder perspectives, (4) demonstrate scepticism towards information and (5) recognise affordances and limitations of science in the resolution of SSI (Zeidler et al., 2019). The third dimension, to examine issues from different perspectives, seems particularly important for developing nuanced reasoning and realising that complex issues have no simple solutions. Such perspective-taking requires commitment to other people and their circumstances, empathy, openness and respect for others' opinions, in the context of issues involving a moral dimension (Zeidler et al., 2019).

It can therefore be assumed that to practice perspective-taking, students need opportunities to discuss issues that they find relevant and that involve stakeholders with whom they can identify. Accordingly, different forms of discussion, argumentation and decision-making have been brought forward as essential elements of teaching (Ratcliffe & Grace, 2003; Zeidler, 2014) and have been shown to promote different learning outcomes. For example, group discussion can promote students' recognition of the complexity of issues as well as their understanding of the relevance of scientific knowledge for the resolution of SSI (Ottander & Simon, 2021; Rudsberg & Öhman, 2015). Alongside discourse-based activities, design-based studies have suggested that students need opportunities to engage with scientific practices such as sampling, recording and reporting data and modelling (Sadler et al., 2017).

In sum, an array of objectives, content and methods may be relevant when incorporating SSI into science teaching. When planning and implementing teaching, teachers must thus make several considerations.

Challenges in Incorporating SSI into Science Teaching

Connecting school science to societal contexts and making room for discourse-based activities may lead to teachers having to reconsider and transform their teaching practices in different ways. Teachers may need to expand their traditional role as conveyor of scientific knowledge and find an appropriate level of control of learning activities, which can be challenging (Bossér et al., 2015; Lee & Yang, 2019). Studies indicate that science teachers tend to focus on covering disciplinary content (Bossér et al., 2015; Tidemand & Nielsen, 2017), thus limiting the space for student perspectives in classroom discourse. This may be because teachers are influenced by traditions of school science with a focus on the transmission of disciplinary knowledge (Leden et al., 2020; Limbere et al., 2022). It may also be challenging for teachers to find an appropriate balance between social and scientific aspects when incorporating SSI into science teaching (Minken et al., 2021).

Research also shows that teachers need to support student adaption to new requirements and classroom norms. Students who are used to reproducing knowledge and dealing with tasks that have a single right answer may find it challenging to ask their own questions to inquire (Amos & Levinson, 2019) and to explore multiple perspectives on SSI (Bossér et al., 2015). They may also find it difficult to deal with the insecurity associated with issues that lack a right answer and strive to arrive at a solution quickly (Lee et al., 2020). Sometimes, such insecurity leads to resistance from students towards new requirements (Bossér et al., 2015; Zeidler et al., 2011).

Considering these challenges, there has been interest in investigating teachers' professional development associated with incorporating SSI into science teaching. Results suggest that it is vital that teachers' beliefs and values regarding teaching and learning are aligned with the intended changes in practice (Friedrichsen et al., 2021) and that teachers remain ownership of teaching during processes of change (Holbrook, 2008). Furthermore, results suggest that most teachers improve teaching practices as they gain first-hand experience with incorporating SSI (Bossér et al., 2015; Bayram-Jacobs et al., 2019). However, research on teachers' development of their knowledge and practices in this field is still scarce (Bayram-Jacobs et al., 2019). There is a need to enhance understanding of how teaching can be developed to foster scientific literacy and how teachers may be supported in this process (Chen & Xiao, 2021; Friedrichsen et al., 2021; Sadler et al., 2017).

Aim and Research Questions

This study examined the knowledge, considerations and actions involved when two teachers incorporated SSI into science teaching. It aimed to identify and describe conditions for developing teaching to promote students' functional scientific literacy.

The study was guided by the following research questions:

- How do the teachers consider the role of content and content knowledge in the promotion of functional scientific literacy?
- What are the teachers' considerations regarding organisation and enactment of teaching?

Theoretical Framework

The study took as its point of departure a view of didactics, or *Didaktik*, as defined in Northern Europe and Scandinavia, as a theory of institutionalised teaching and learning (Hudson, 2002, 2003). Didactics provides a framework for reflecting on educational questions concerning purpose, objectives, content and methods. It emphasises reflection on how teaching can prepare students for active and responsible citizenship (Hudson, 2002), which is in accord with the overarching purpose of incorporating SSI into science education. This involves considering the context of teaching, which means that teaching is understood in relation to both school and societal conditions and goals. In other words, it pays attention to the ways in which the teacher's considerations, decisions and actions are framed by, for instance, local and national curricula, parents' expectations or prevailing traditions and places the teacher in a mediating position between the school and wider society and the specific teaching-studying-learning situation (Uljens, 1997). In this respect, didactics contains a critical element which implies "reflection on relations between school and instruction on the one hand (their goals, contents, forms of organisation and methods) and social conditions and processes on the other" (Klafki, 1995, p. 14).

Moreover, didactics takes as its point of departure that teaching and studying are intentional activities that can only be understood in relation to their aims and purposes. Didactics recognises that teaching depends on the teacher's capacity to make informed judgements in relation to the specific teaching-studying-learning situation and the prescribed curriculum (Hudson, 2002). This means that intention, action and evaluative reflection are necessary elements of teaching because there is no guarantee that teaching leads to the intended learning. In addition, viewing both teachers and students as intentional subjects enables an understanding of teaching and learning as processes of interaction in terms of shared activity in relation to content, aims and purposes (Uljens, 1997).

This study set out to analyse and describe the process by which two teachers negotiated, reconsidered and transformed teaching practices for student development of functional scientific literacy within prevailing conditions. For this purpose, the didactic triangle (Fig. 1), a model that illustrates essential relations between the teacher, the student(s) and the content in the teaching-studying-learning situation (Hudson, 2002), was used as an analytical lens.

Based on the didactic triangle, the teacher's work can be analysed in terms of a set of relations. These are (1) the relation between the teacher and the content; (2) the relation

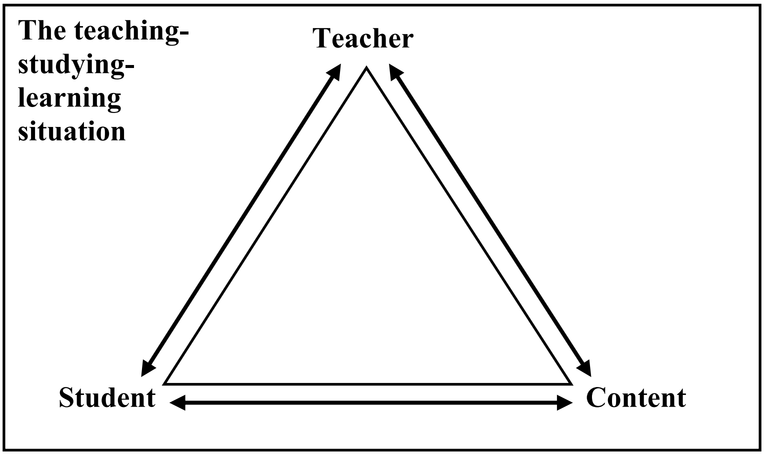

Fig. 1 Didactic triangle illustrating relations between the teacher, student(s) and content in a teaching-studying-learning situation (Hudson, 2002; Hudson & Meyer, 2011)

between the teacher and the students' relation to the content, called *the didactic relation*; and (3) the relation between the teacher and the student(s), called *the pedagogical relation* (Hudson, 2002). As regards the relation between the teacher and the content, this concerns the teacher's content knowledge as well as interpretation and transformation of the curriculum (Kansanen & Meri, 1999), in terms of the selection of content for teaching, and learning goals for students with respect to the content. The didactic relation concerns the teacher's organisation and enactment of teaching to facilitate studying of the content by the specific group of students (Hudson, 2002), including strategies concerning how to make content accessible and comprehensible to students (Klafki, 1995) and clarifying learning objectives for students (Hudson & Meyer, 2011). The pedagogical relation unfolds through interaction and emphasises the teacher's responsibility for taking the students' best interest into account (Kansanen & Meri, 1999).

In the study, this set of relations (1)–(3) was considered in the analysis.

Methods

Study Context and Participants

The setting of this study was an upper secondary school in Sweden and the subject "science studies", which is compulsory for all students not specialising in science or technology. In Sweden, the syllabus for each school subject is goal-oriented with descriptions of the aims of the subject, core content to be covered and requirements for different grades. This leaves freedom for teachers to specify content and organise classroom work, provided that the learning objectives can be reached. The subject covers aspects of sustainable development, human sexuality and relationships, individual health and lifestyle and biotechnology and its implications. One of the subject's aims is that students "develop an understanding of how scientific knowledge can be used in both professional life and everyday situations". By taking part in discussions on societal issues related to science, students should also have opportunities to develop science knowledge "to be able to meet, understand and influence their own contemporary conditions" (Skolverket., 2011, p. 1). It can thus be concluded that one aim is the development of functional scientific literacy.

The study involved two teachers, Karen and Matt, working at a public school with approximately 2000 students in a large municipality. The participating teachers hold teaching degrees in science studies, and they had 20 and 4 years of teaching experience, respectively, at the time of the study. The teachers were interested in developing their teaching practices to promote students' functional scientific literacy by providing opportunities for students to explore SSI. They had applied for and received resources from the local school development department in terms of time allotted in their schedules for a year-long professional development project. The author of this study was invited by the teachers to act as a facilitator, or "critical friend", in the process, based on their knowledge of her previous research.

The teachers were invited to participate in this study in accordance with Swedish ethical guidelines for social science research (Swedish Research Council, 2017). Written consent to participate was received from both teachers. Pseudonyms are used throughout the account to preserve participant confidentiality.

Professional Development Project

When applying for resources to perform the professional development project, the teachers wrote a project plan where they described perceived challenges with respect to the goal of promoting students' functional scientific literacy. The challenges concerned student difficulties in using scientific content knowledge in reasoning about SSI and adapting to teaching practices involving complex tasks that do not have a single right answer. These challenges constituted the point of departure for the transformation of teaching practices in designing teaching that makes science content accessible to students and that encourages collaborative exploration of multiple perspectives on SSI.

The teachers made an overall plan for four teaching units in science studies that were to be implemented and evaluated in one class in the first year of the Economics Programme (15–16-year-old students) and one class in the second year of the Social Science Programme (16–17-year-old students) during an academic year (42 weeks in total). The themes of the units were substances that affect the brain, genetic engineering, sexuality and relationships and sustainable development. Each unit spanned 6–12 weeks and comprised approximately 3 hours of teaching each week. Teaching was based on principles that the topic should be interesting and relevant to students and that the content should enable the exploration of the structure and function of matter (Klafki, 1995). Each unit was structured similarly, starting with articles or films to introduce the topic. The students then formulated questions to explore further, and the teachers provided reading, lectures, laboratory exercises and supervision during the process. Then, the students wrote a paper summarising their exploration. Finally, the students, in groups, read each other's papers, formulated questions for group discussion and conducted a discussion on the topic as a culminating experience. The student papers and the discussions formed the basis for formative and summative assessment vis-à-vis the requirements for different grades stated in the syllabus. These are aligned with aspects of functional scientific literacy and concern, for example, students' ability to use scientific knowledge to put questions and give explanations and arguments in discussions on issues (Skolverket., 2011).

The teachers met on average once every 2 weeks to reflect on completed teaching, reconsider decisions and readjust their planning. Thus, several cycles of evaluation and adjustments in practice were carried out during each unit. To stimulate reflection and facilitate evaluation of the effects of actions, the teachers recorded actions and observations throughout the process, as recommended by Kemmis et al. (2014). They wrote records of the lessons they taught. The records comprised notes about actions, observations, interpretations and feelings, as well as evaluations of student learning in relation to teaching, curriculum and assessment. They also made field notes during observations of each other's lessons.

Inspired by participatory approaches to action research (Kemmis et al., 2014), the teachers invited the author to act as a critical friend during their regular meetings. The teachers and the researcher met via a video conference tool, and these meetings were audio recorded. The teachers shared their planning, teaching material and written records of lessons and field notes of observations with the researcher. This shared documentation, together with issues addressed by the teachers during meetings, formed the basis for collaborative inquiry and reflection. The researcher proposed alternative interpretations, provided reading or presented results from educational research and suggested strategies to consider for action. However, final decisions regarding teaching and evaluation were made by the teachers, collectively and individually.

Data Collection and Analysis

The data for the present study consist of the teachers' written records of teaching, their observation field notes and transcripts of the recorded meetings between the teachers and the researcher. It was assumed that the teachers' didactic considerations would be visible in this selection of data. The teachers' initial project plan, their teaching planning and teaching material were consulted, when necessary, to provide background information and facilitate the interpretation of data but were not included in the analysis.

The analysis was performed in three steps. First, pieces of data that concerned each of the relations involving the teacher, illustrated in the didactic triangle (Fig. 1), were identified and grouped. Table 1 presents how relations (1)–(3) were defined for analytical

Table 1 Definition of didactic relations employed in the analysis, as interpreted in the context of teaching aimed at promoting students' functional scientific literacy

Relation	Teacher reflections concerning
(1) Teacher—content Concerns the teacher's content knowledge and the teacher's interpretation and transformation of the curriculum in terms of learning goals and content selection (Kansanen & Meri, 1999)	- The teachers' science content knowledge - What students need to know to be able to negotiate SSI - Selection of content relevant to the negotiation of SSI
(2) The didactic relation Concerns organisation and enactment of teaching to facilitate the specific group of students' studying of the content (Hudson, 2002; Hudson & Meyer, 2011; Klafki, 1995)	- Communication of learning objectives and assessment of learning - Organisation and enactment of teaching-studying-learning activities to explore multiple perspectives on SSI - Making science content accessible and comprehensible to students
(3) The pedagogical relation Concerns the teacher's responsibility for taking the students' best interest into account (Kansanen & Meri, 1999)	- Supporting students faced with new requirements associated with the incorporation of SSI

purposes, by interpreting their meaning in the context of teaching aimed at promoting functional scientific literacy through the incorporation of SSI.

Second, the grouped data that concerned each of the relations (1)–(3) were analysed separately, and codes were assigned inductively to capture ways in which each relation was displayed in the data. Finally, commonalities or distinguishing features between initial codes were explored through an iterative process to construct final themes in relation to the research questions (Robson, 2011).

Excerpts that were judged to be representative of the results were translated into English and are presented in the "Results" section, together with notes on the researcher's interpretations, to enable the reader to judge the validity of interpretations (Robson, 2011). There were also instances of peer debriefing regarding interpretations to guard against researcher bias. Segments of excerpts that were judged irrelevant for the purpose of illustrating interpretations are omitted, indicated by backslashes: /…/. Notes between square brackets ([]) indicate clarifications made by the researcher.

Results

Role of Content and Content Knowledge in the Promotion of Functional Scientific Literacy

Three themes identified as concerning the relation between the teachers and the content were constructed based on the analysis of the teachers' reflections. These are described below and concern the teachers' conceptualisations of content relevant to negotiate SSI, what students need to know to be able to negotiate SSI and the teachers' science content knowledge.

Teachers' Conceptualisation of Content Relevant to Negotiating SSI

It appears that a point of departure in teaching was that student knowledge of scientific facts and principles is a prerequisite for understanding SSI and thus an important element of functional scientific literacy. The science content seemed to be selected on a need-to-know basis and consistently connected to current societal issues. This is illustrated in the following excerpt, where Matt reflects on what took place during a lesson in the teaching unit "substances that affect the brain". The students were conducting lab work to investigate the solubility of pigments in carrot and beetroot in water and oil.

> Many of the students work scientifically in such a way that they compare and discuss what they observe in a very good way. /…/ Some students also highlight the importance of several replicates and the controls during the summary, which also shows that they have understood the scientific approach. /…/ The main thing is that they understand the connection between different solubilities, the structures and properties of the molecules and the blood-brain barrier. As I said I think they seem to be picking this up quickly. They seem to have grasped the proximate purpose of understanding principles of solubility and I also think the connection to their substance and drugs forms a clearer overall purpose. (Matt, observation field notes, week 8)

Here, it appears that science content in terms of solubility, molecular structures and function of the blood-brain barrier is connected to specific substances that affect the brain and that the students are investigating, that is, “their substance”, in relation to SSI concerning drugs in society. This excerpt also illustrates that scientific practices and elements of a scientific approach were considered relevant content to address. This concerned elements of conducting experiments, such as observation and replication as described above, but also aspects of reviewing trustworthiness of sources of information and their usefulness in relation to answering different kinds of questions.

Value-laden content in terms of ethical considerations, societal norms and personal values also emerged as significant. For example, during a classroom observation in the unit “genetic engineering” where the students formulated questions that they wished to explore further, Karen wrote:

> Questions like “Designer babies- good or bad?” need to be challenged with questions concerning “for whom?” Conflicts of interest may need to be spelled out more clearly in the assignment. (Karen, observation field notes, week 23)

This can be interpreted as when dealing with implications of genetic engineering, such as the possibility of “designing” babies, ethical considerations need to be made. This involves considering consequences for different stakeholders potentially affected by the issue.

Particularly in the teaching unit “sexuality and relationships”, the teachers also emphasised the importance of addressing societal norms as well as personal values. It appeared that they introduced science content that was supposed to challenge prevailing norms, for example, “notions of femininity and masculinity /…/ linked to regulation of the formation of germ cells” (Matt, record of teaching, week 32). In this way, science content in terms of biological similarities alongside differences between the sexes was utilised to question taken for granted notions of gender.

What Students Need to Know to Be Able to Negotiate SSI

It appeared to be a challenge for the teachers to estimate what students need to know to make informed decisions on SSI, that is, selecting appropriate content. As was written by Karen while observing a lesson in the unit “genetic engineering”:

> What is a citizen level to understand the complexity? Basically, we don’t want them to be deceived by e.g. the marketing of gene tests. (Karen, observation field notes, week 18)

Karen expresses a clear idea of a dimension of functional scientific literacy that she wants to promote among her students. However, it is not clear to her what level of science content knowledge is sufficient in this respect. This dilemma was also addressed by Matt:

> It may simply be enough if we get the students to understand that the issues [regarding genetic engineering] are extremely complex in some cases. If they understand that they cannot understand exactly how different genes affect e.g. a certain characteristic, they may be able to understand that it is difficult to draw conclusions about how a genetic test can be good or bad for an individual. (Matt, record of teaching, week 16)

Here, it is suggested that student understanding of the inherent complexity of the relationships between different genes and human traits is one essential aspect of scientific literacy in relation to biotechnology. However, the complexity of the issue relates to science content in terms of the structure and function of genes.

Teachers' Science Content Knowledge

From the teachers' reflections, it also emerged that their own profound science content knowledge was crucial for them to be able to support student investigations of SSI.

> The students started to ask things on a cellular and molecular level about what happens during inbreeding and I tried to give an overview with the help of crossing schedule and dominant and recessive traits. In connection with that, concepts such as allele also appeared. (Matt, record of teaching, week 33)

It appears that Matt used his science knowledge to meet the students' curiosity and questions that arose during their exploration of inbreeding. Matt also notes the importance of expansive science knowledge in his observations of Karen's teaching:

> It becomes clear that Karen has a high level of subject knowledge and that this is something that is important to being able to be free in her teaching and to have more of a guiding role for the students. Then the students can start with their questions and Karen can pick up on these questions. (Matt, observation field notes, week 24)

Here, Karen's science content knowledge is related to the possibility of supervising students based on their questions. This can be related to the teachers' quest to promote an explorative approach among students, which will be further described in the next section.

Creating a Classroom Culture that Supports Evidence-Based Exploration of SSI

Based on the analysis of the didactic relation, as expressed by the teachers' reflections, two themes were constructed that concern how to support students' evidence-based exploration of SSI. The first theme describes how the teachers worked to create an explorative classroom culture characterised by student engagement with content and encouragement of collaborative efforts to make meaning. The second theme concerns ways to facilitate students' evidence-based reasoning. The quest to promote an exploratory approach among students also impinged upon the pedagogical relation, as reflected by a third theme describing how the teachers struggled to support student adaption to new requirements. Below, each of the three themes is described.

Creating an Explorative Classroom Culture

Aiming at creating an exploratory classroom culture, the teachers promoted student engagement with content in different ways. With respect to classroom interaction, the teachers aimed to consistently urge students to rephrase information retrieved from different sources.

> In order for it to be visible to us and also to them what they have understood or what they are wondering, it is great to summarise, repeat or rephrase in some way, you explain with your own words, and like you [Karen] highlighted /…/ this is something you want to spend time on but also need to practice [to ask students to do]. (Matt, meeting with researcher, week 22)

In a similar vein, Karen expressed that what she wanted to achieve was to "teach the students to learn by listening, asking questions, rephrasing others' questions and answers" (Karen, record of teaching, week 38). Accordingly, the teachers aimed to make content relevant for students by encouraging them to ask their own questions to explore and by delving into student questions.

The excerpt below concerns a lesson where first-year students were invited to take part in second-year students' presentation of websites that they had designed with information on human sexuality and relationships.

> It was so clear to me that the groups that chose questions that concerned them /…/ and had worked on understanding norm criticism showed high quality: they were confident when presenting and leading conversations, the website was cohesive and they brought relevant, pressing questions for discussion. /…/ This is what I've been longing for /…/ Getting to do more authentic tasks that mean something outside the walls of the classroom. (Karen, record of teaching, week 28)

Karen emphasises the importance of students' exploration of issues that concern them and connecting classroom activities with real-life contexts that matter to students. This ambition was also reflected in the need to raise questions among students, as illustrated in the following excerpt:

> The students need support when it comes to what to ask questions about. /…/ I also think that lectures, movies might be good to show to sort of provoke something here. Perhaps you can show something more controversial and something where students obviously know there are things to discuss to lead them into the exploration and questioning. (Matt, observation field notes, week 15)

In contrast to reproducing content, the teachers also promoted students' engagement with content by encouraging them to contextualise concepts, for example, by making their own representations as illustrated by the excerpt below:

> The students had been given homework which is about connecting all the concepts that have come up during the conversations about how a plant works and how the dome [a self-sufficient dome on Mars where humans could survive] should work. Mind map with the concepts and then connect the words with a picture of a potato growing and a person about to eat a potato. (Karen, record of teaching, week 39)

Collaborative effort to make meaning was also encouraged as part of the explorative classroom culture that the teachers aimed to create:

> A group of three people worked very well and had taken out books and read about CB1 receptors. But they needed help understanding. I asked them if they had talked and discussed with each other and gone through the text together. They said they hadn't. I encouraged them to do so and try to overlook the fact that they must "get it done" by dividing the work. (Matt, record of teaching, week 8)

Facilitating Evidence-Based Reasoning

From the teachers' reflections, it appeared that they used different strategies to facilitate students' evidence-based reasoning in relation to SSI. For example, they structured content to make it comprehensible to students and to facilitate the exploration of both scientific and societal perspectives on SSI.

> I started the lesson by describing the different levels one can use in natural science (molecule – cell – organ – individual – population – society – ecosystem – Earth). I linked this with suggestions on how they can structure their text, that is, they start with a socioscientific issue and then dive into the molecular and cellular level because that's where we've been a lot in our exploratory work, but towards the end of the text they can zoom out on an individual and societal level to tie it all together. (Matt, record of teaching, week 12)

During the school year, the teachers repeatedly referred to the structure of matter and different levels of scientific explanations of the functions of living organisms, from the molecular level to the levels of individuals, populations or entire ecosystems. This offered opportunities for students to learn about the structure of matter, to become familiar with exploring how different levels are connected and to realise that evidence-based reasoning on SSI typically requires understanding of underlying science content.

Moreover, the teachers promoted evidence-based reasoning and a scientific approach to dealing with SSI. The following excerpt concerns a group discussion where students discussed whether cannabis should be legalised in Sweden.

> Many students used expressions like I think, I know, etc. when it came to the idea that, e.g., the legalization of cannabis would mean less crime. I then pointed out that they must have sources supporting what they say and that this is a clear example where you must start from some text and some research. Simply basing statements on what you believe where you can't connect it to any type of source is not optimal. Then we easily end up in a discussion that's only about opinions. (Matt, record of teaching, week 13)

Here, Matt describes that he intervenes in the discussion to clarify that reasoning about potential consequences of different courses of action ought to be based on evidence.

Supporting Student Adaption to New Requirements

An impediment to the development of desired teaching practices seemed to be prevailing science teaching traditions and instrumental views of teaching, studying and learning associated with a goal- and result-oriented curriculum. Karen described how:

> Many had experienced the teaching in [compulsory] school as "facts you learn by heart", some also mentioned laboratory work that they mostly seemed to have done to confirm known facts rather than to investigate. (Karen, record of teaching, week 2)

This reflects an approach to science teaching that the students seem to be used to and expect, one focusing on the transmission of facts, as expressed by Matt: "I feel like they're waiting for me to feed them things to learn" (Matt, meeting with researcher, week 4).

In striving to deviate from this approach and promote an exploratory approach among students, the teachers described it as challenging that "there's a resistance in some to work if they do not have a deadline for a product, an exam to study for or something like that" (Matt, record of teaching, week 12). The teachers thus needed to support the students' adaption to new demands and expectations associated with the explorative classroom culture. This placed specific demands on the relation between teacher and students, and the teachers reflected on the importance of mutual trust in this process:

> ... generally, the class has an instrumental view of learning and they find it difficult to take processes seriously, i.e. follow a plan for how to work continuously if there's no clear external control. Somehow I also feel that they don't trust the teacher and they think that the teacher will deceive them. (Karen, record of teaching, week 10)

To build mutual trust and to support the students in the new approach, it was suggested that the teacher needs to be clear about what is expected of the students.

> So the students still want to do it "right", but I still feel that they want to understand and I think it's so good that they can tell me what they find difficult. I'll make it clear that I don't expect them to understand things all at once. (Karen, record of teaching, week 18)

Besides supporting adaption to new demands and expectations, clarity about expectations was also considered to reduce anxiety among students.

> I emphasised that this is the first time we have practiced working in this way. I wanted to reduce the expectations and stress that students can feel because they have "done it wrong". (Matt, record of teaching, week 10)

This illustrates that new approaches to teaching can trigger stress and anxiety in students. Teachers may need to consider this in the process of promoting an exploratory approach among students.

Discussion

The results depict that the incorporation of SSI into science teaching for the promotion of students' functional scientific literacy is a complex endeavour. The teachers organised and enacted teaching in which SSI enabled the introduction of scientific facts on a need-to-know basis, the student practice in evidence-based reasoning and the consideration of values and norms. In line with research that suggests that science content knowledge promotes meaningful engagement with SSI (Lewis & Leach, 2006; Ottander & Simon, 2021; Rudsberg & Öhman, 2015), it appeared that the teachers conceptualised student knowledge of scientific facts and principles as a prerequisite for the negotiation of SSI. For example, in the context of SSI related to biotechnology, knowledge of the structure and function of genes was considered essential for student understanding of the complexity of issues, which the teachers described as an essential element of scientific literacy, as was also proposed by Zeidler et al. (2019). However, the teachers were uncertain as regards the level of knowledge needed by students to make informed decisions on SSI, and they did not seem to arrive at a conclusion on this matter. Nevertheless, the results of the study suggest that student familiarity with the different levels of scientific explanations of the functions of living organisms, from the molecular level to the levels of individuals, populations and entire ecosystems, could be a starting point for exploring science content underlying an issue. This could be the case when, for instance, dealing with SSI concerning drugs or genetic engineering that foreground chemistry- and biology-related content.

In contrast to giving primacy to covering disciplinary content, which seems to be common among science teachers (Bossér et al., 2015; Tidemand & Nielsen, 2017), the participating teachers emphasised the importance of dealing with issues relevant to students and departing from student questions. It can be assumed that the incorporation of issues that students found relevant resonated with the teachers' expressed aspiration to encourage students to examine SSI from different stakeholder perspectives, which may be facilitated by genuine interest on the part of students. In this way, perspective-taking, which requires consideration of other people's circumstances (Zeidler et al., 2019), can be promoted as a dimension of students' scientific literacy. However, as also suggested by Amos and Levinson (2019), the results show that teachers may need to consider strategies to raise questions among students. Moreover, responding to student questions required profound science content knowledge on the part of the teachers. This is a dimension of science teachers' professional knowledge that risks being neglected in professional development initiatives, which tend to focus on previously reported challenges, such as science teachers' predominant focus on subject knowledge and challenges with student-centred teaching practices (Bossér et al., 2015; Lee & Yang, 2019). Emphasising science teachers' knowledge in their subjects as a prerequisite for the development of student-centred teaching practices may counterbalance a deficit view of teachers' professional knowledge and empower teachers in their quest to transform teaching practices to promote students' scientific literacy.

Supporting Scientific Literacy Within Existing Conditions

The framework of didactics emphasises teaching and learning as a shared activity in relation to content, aims and purposes (Uljens, 1997). It can therefore be assumed that when teachers and students do not share the same goals, as can be the case when teachers work to transform traditional teaching practices that students are familiar with, this may jeopardise the enactment of shared activity in relation to purposes, which forms the foundation for meaningful teaching-studying-learning activities. This may be a reason why the teachers had to deal with tensions that arose between some students' instrumental views of learning associated with the goal- and result-oriented curriculum and the promotion of an exploratory approach. The purpose and overarching goal of teaching-studying-learning activities, that is, the development of functional scientific literacy, seemed clear to the teachers and guided their considerations. However, in line with research performed in different contexts (Bossér et al., 2015; Lee et al., 2020; Zeidler et al., 2011), these goals often seemed not to be shared by the students. Based on their previous educational experiences, the students focused on the achievement of requirements for certain grades and expected the teachers to transmit knowledge. The teachers had to put considerable effort into supporting student adaption to new demands and expectations, and the results show the importance of mutual trust and clear expectations in the process to reduce student anxiety about new requirements.

The results thus illuminate that there may be impediments inherent to development of shared activity within the frames of existing traditions and the mandatory curriculum. On the one hand, students individually tend to focus on the reproduction of facts and the achievement of requirements for specific grades. On the other hand, the promotion of scientific literacy may require the creation of an explorative classroom culture characterised by collaborative efforts to make meaning, as the results of this study suggest. It would therefore be useful to research further what is reasonable to expect and possible to achieve as regards the incorporation of SSI within existing conditions in different educational contexts.

The Intertwined Character of Relations Between Teacher, Content and Students

The definition of the relations involving the teacher (Table 1), illustrated in the didactic triangle (Fig. 1), implied reducing complexity for analytical purposes, as in any teaching-studying-learning activity, these relations are interrelated and intertwined (Hudson & Meyer, 2011). This is well illustrated by this study's results. For example, the teachers consistently considered how best to select content relevant to the chosen SSI, and they structured the content in a way as to foreground selected scientific phenomena. This means that the teachers' content knowledge and the selection of content appropriate for teaching (the relation between the teacher and the content) were interrelated with strategies to make content comprehensible to students (the didactic relation). Similarly, the teachers' promotion of an exploratory approach among students (the didactic relation) was intertwined with the teachers' support of the students in this process (the pedagogical relation). Taken together, the results illustrate the network of considerations involved in transforming teaching practices. This is important to consider in professional development initiatives where the promotion of specific teaching strategies may be insufficient to transform practices because it fails to consider the entirety of the teaching-studying-learning situation.

Limitations

Previous research emphasises the importance of teacher ownership during processes of change (Holbrook, 2008) and suggests that it is vital that teachers' beliefs and values regarding teaching and learning be congruent with intended changes in practice (Friedrichsen et al., 2021). The teachers in this study incorporated SSI to promote students' functional scientific literacy based on their own beliefs and values, and the results may not be representative of what would be achieved by other teachers urged to incorporate SSI. For instance, the teachers in this study did not seem reluctant to depart from their authoritative position as conveyors of scientific knowledge, which has often proved challenging for science teachers (Limbere et al., 2022). Nevertheless, some of the results, for example, the challenges related to dealing with student expectations of a more traditional approach to science teaching, are in line with previous findings (Bossér et al., 2015; Lee et al., 2020; Zeidler et al., 2011) which suggest that they are not unique. It is therefore reasonable to assume that some of the findings of the present study may be transferable to other contexts.

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Declarations

Consent to Participate The participants were informed about the overall purpose of the research and invited to participate in accordance with Swedish ethical guidelines for social science research. These guidelines call for informed consent on the part of all participants, and for participants to be able to withdraw from the study at any time. A further ethical requirement is that confidentiality of the participants should be protected. Informed consent to participate was received from the participating teachers.

Conflict of Interest The authors declare no competing interests.

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