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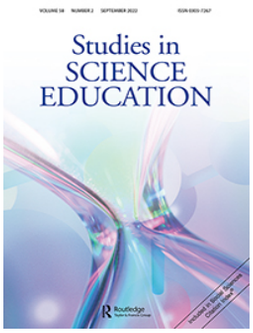

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Supporting Secondary Students' Morality Development in Science Education

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ABSTRACT

This review study synthesises 28 empirical research articles emphasising the learning of morality aspects in the context of addressing socioscientific issues (SSI) in secondary science education. The key interrelated questions we seek to address in this study are how morality is conceptualised in the science classroom in the light of emerging sustainability issues and how it can be developed. We used the Four Component Model of Morality to create a knowledge base for how morality has been conceptualised in the literature on secondary science education and how it can be developed. The findings of this review study show that not all studies have used concrete, explicit conceptualisations of morality and that the role of sense of place and the situatedness of morality have often been neglected. It also emerged that studies focusing on students' moral character and action-taking were underrepresented. We recommend that further research be carried out on the interrelationships between moral character and enacted moral reasoning. The review also reveals a gap between morality research and teaching. Based on the outcomes of this review, we propose a set of recommendations aimed at guiding and encouraging students' morality within secondary science education.

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Socioscientific issues; morality; four component model; secondary science education

Introduction

Humanity faces important challenges in creating a sustainable future, including climate change, food quality and security, increased likelihood of pandemics, water and air pollution, extreme droughts, floods and loss of biodiversity. Many of these challenges are addressed in the 17 Sustainable Development Goals (SDGs) that form part of the United Nations' Agenda 2030 (UNDP, 2019). Science educators and schools around the world are looking for ways to meaningfully engage their students in these issues. Doing so is not easy, as many of these issues are 'wicked' in the sense that they are invariably ill-defined, ambiguous, value-laden and highly contextual (Dreyfus et al., 1999; Gibson & Fox, 2013; Jickling, 1992). In today's globalised and highly interconnected world, students and educators alike often find themselves surrounded by a surplus of information, but they have little guidance on how to judge that information in terms of its validity, ethical underpinnings and moral implications. In the words of E.O. Wilson: 'We are drowning in

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information while starving for wisdom' (Wilson, 1998, p. 249). Questions about how to reduce our ecological footprint, whether nuclear energy is sustainable, how meat consumption affects climate change, whether herd immunity is a good strategy in dealing with a pandemic – all require both scientific literacy and the ability to make moral judgements based on the information available. This review focuses on the latter, as science educators often find it difficult to deal with moral questions, dilemmas and ethics in their classrooms, tending instead to shy away from them (Bennett et al., 2010; Day & Bryce, 2011; Grace, 2009; R. Levinson & Reiss, 2003; Oulton et al., 2004).

The key interrelated questions we seek to address are how morality is conceptualised in the science classroom in the light of emerging sustainability issues and how it can be developed. In responding to these questions, we offer a synthesis of the literature on factors influencing students' moral sensitivity, the nature of students' moral reasoning regarding socioscientific issues (SSI) and pedagogical strategies to promote the development of such reasoning. We also provide a synthesis of the literature on factors influencing student motivation and character, or student actions. As with any review study, we limit our search to a selection of the literature and we describe the set of inclusion criteria we used under Methods.

Recommendations are made for a research agenda on morality and SSI and how it can be made an integral part of the school's science curriculum and science education practices. We do so by reflecting on the concept of morality within moral education and on the philosophical and pedagogical considerations that could or should be taken into account.

We first lay the conceptual foundation for the review by providing a brief analysis of the occurrence of moral reasoning and morality within the context of SSI, and then introduce the Four Component Model of Morality that we used in reviewing the literature.

Moral underpinnings of socioscientific issues

One entry point for addressing wicked sustainability issues in science education is to treat them as socioscientific issues[1] (SSI). Over the years, SSI and research on the teaching of SSI in science education has yielded a vast body of research and practices that provide useful insights into how science education can engage meaningfully with sustainability challenges.

The idea of teaching through SSI has been widely recognised in the international science education community (D.L. Zeidler & Keefer, 2003; Driver et al., 2000; Duschl & Osborne, 2002; Patronis et al., 1999), in many countries' national policy documents (e.g., ACARA, 2021; NRC, 2012) and in international education guidelines (e.g., European Commission, 2015; UNESCO, 2016).

The conception of teaching science in its societal context has already been made by earlier approaches to science education. Exemplary for this are the science-technology-society (STS) approach (e.g., Aikenhead, 1994; Fensham, 1988) and the science-technology-society-environment (STSE) approach (e.g., Pedretti, 2003; 2005). An important criticism of the STS approach was that it failed to combine epistemological issues with sociocultural factors and ethics, and other considerations (e.g., Hipkins et al., 2005; Zeidler et al., 2005).

SSI as an approach to science education met this criticism by emphasising the impact of decisions in science and technology on society, as did the STS approach, while also considering the 'ethical dimensions of science, the moral reasoning of the child, and the emotional development of the student' (Zeidler, Walker, Ackett, & Simmons, 2002; p. 344).

Zeidler, Sadler, Simmons, and, & Howes (2005) demonstrated that SSI science education was better able than the STS(E) approach to combine the acquisition of knowledge about the nature of science with the acquisition of argumentation skills, the development of reflection on values and forming a moral judgment. SSI science education thereby contributes to the development of functional scientific literacy (D.L. Zeidler & Keefer, 2003), which here refers to Vision II on scientific literacy (Roberts, 2007), with a greater focus – more so than in Vision I, which is concerned with promoting the academic content goals of science – on informed decision-making when confronted with multiple perspectives and scientific and moral dilemmas (Sadler, 2004a; Zeidler et al., 2005). The latter aspect is also emphasised by D.L. Zeidler and Keefer (2003), who argue that SSI 'are equated with the consideration of ethical issues and the construction of moral judgements about scientific topics via social interaction and discourse' (p. 8).

Much like wicked sustainability issues, SSI have the following key features. They are ill-structured in that they lack definitive solutions and are subject to multiple perspectives (Sadler, 2004a), inquiry and scepticism (Albe, 2008; Colucci-Gray et al., 2006; Sadler et al., 2007; Simonneaux & Simonneaux, 2009). SSI are typically value-laden; in other words, individual moral considerations play a role in the moral reasoning process and the resulting decision-making process regarding SSI (Hogan, 2002; Pedretti & Hodson, 1995; Fleming, 1986; Zeidler, Walker, Ackett, & Simmons, 2002; Sadler, 2004b; Sadler & Zeidler, 2004; Bell & Lederman, 2003). Based on this vision, attention to ethics and morality within SSI science education is of great importance.

SSI and morality

There are comprehensive potential benefits for emphasising ethics and morality in the context of SSI science education. One major contribution is the development of students' functional scientific literacy (D.L. Zeidler & Keefer, 2003; D. L. Zeidler & Lewis, 2003; Sadler, 2004b; Zeidler et al., 2005). Within this vision on scientific literacy, there is a strong focus on informed decision-making when confronted with multiple perspectives in scientific and moral dilemmas. Reiss (2006) distils from this that paying attention to ethics in science education contexts potentially helps boost ethical knowledge and improve ethical judgment (Reiss, 2006), including the development of social responsibility (Finegold, 2001). According to Gutierez (2015), a focus on ethics in the context of SSI potentially enhances 'bioethical maturity', which is postulated in the Universal Declaration of Bioethics and Human Rights (UNESCO, 2006). Bioethical maturity is conceptualised by Macer (2004) as the ability to recognise the different ethical frameworks that are used to consider ethical dilemmas. This includes the ability to understand a variety of ideas, to balance the benefits and risks of science and technology and to use reasoned approaches in making decisions that combine scientific data with ethical views (Macer, 2004).

The moral nature of SSI (Fowler et al., 2009) entails the need to foster student sensitivity to the moral nature of SSI, and encourages them in their moral reasoning and decision-making processes with a view to forming a moral judgment (D.L. Zeidler & Keefer, 2003; Fowler et al., 2009; Zeidler et al., 2005). These aspects are part of someone's 'morality',

a concept that has been extensively explored in the context of moral psychology (e.g., Narvaez & Rest, 1995; Rest et al., 1999). Various studies have shown that students often recognise and experience SSI as moral problems (Bell & Lederman, 2003; Pedretti & Hodson, 1995; Sadler & Zeidler, 2004), reflecting their moral sensitivity. A condition for recognising and acknowledging the moral aspects of an SSI is the perception of moral emotions, such as empathy, guilt, compassion and care (Rest et al., 1986). This is congruent with other findings from moral psychology, which show that moral emotions are central aspects of morality (Belenky et al., 1986; Berkowitz, 1997; Eisenberg, 2000). Research by Sadler and Zeidler (2005) in post-secondary science education provided evidence that emotions are often central to students' moral reasoning. Their research showed that even well-formulated arguments are largely driven by emotions, which illustrates the affective aspect of morality.

Various, more recent studies have also demonstrated the role of emotions in students' moral reasoning. For example, regarding the nature of students' emotive reasoning, Herman et al. (2020) demonstrated that, within place-based environmental SSI instruction, post-secondary students' emotive reasoning consists of a range of emotions and moral sentiments (e.g., from apathy to empathy about a topic). Similarly, research conducted with a group of 14–15-year-old students also showed that, within SSI-based instruction on gene technology, students become more compassionate towards the various stakeholders in the technology, reflecting their sense of responsibility for the future resolution of genetic SSI (Lee et al., 2013).

In addition, research has shown that students rarely appeal solely to their scientific knowledge in their moral argumentation and decision-making, and that their reasoning is often primarily based on values (Bell & Lederman, 2003; Grace & Ratcliffe, 2002; J.A. Nielsen, 2012a; Kolstø, 2006; Means & Voss, 1996; Sadler & Zeidler, 2005; Voss & Means, 1991). Other research has shown that students' prior experiences (Öhman & Östman, 2007), prior beliefs and personal consequences (Sadler & Zeidler, 2004), as well as their cultural standpoints (Braund et al., 2007), influence their moral argumentation and decision-making with regard to SSI. The quality of their arguments takes an important place within students' moral reasoning in SSIs. Students' argumentation in science education has been extensively researched, and Toulmin's argumentation framework is oftentimes used to evaluate students' argumentation quality (e.g., Driver et al., 2000; Erduran et al., 2004; Kelly & Takao, 2002; Osborne et al., 2004; Venville & Dawson, 2010; Zeidler et al., 2003).

While Toulmin's model can be useful, it does have limited significance in analysing students' arguments (e.g., Evagorou et al., 2011). An important reason for this is that the model focuses on the field-independent part of arguments. However, in moral argumentation in SSIs the context is highly important, and the topics are open for debate and invite to ponder on justifications and objections. The argument, as a result of the reasoning, often concerns open-ended, ill-structured real world problems without one conclusive, correct response (cf. V. Dawson & Carson, 2017). For instance, Kolstø (2006) argues that since students often rely on personal or generally accepted values, it is legitimate to use these values as criteria or warrants in moral argumentation regarding SSIs. Furthermore, J. A. Nielsen (2012b) found that science content played a limited role in students' moral argumentation and decision-making. In cases when science content was used, students often used it to frame the issue in such a way that the knowledge was beneficial to support the student's argument.

The information above illustrates that there is already considerable knowledge available about the role of morality in SSI, and that attention to aspects of morality is indispensable in addressing SSI. However, this does not mean that morality is always central to SSI science education. In the next section, we discuss the role of morality in science education further.

Morality in the context of SSI science education

Simmons and Zeidler (2003) argue that learning about SSI encourages students' critical thinking and their understanding of the nature of science, as well as their moral reasoning. They also argue that SSI helps students to deal with the moral aspects of such issues, since they encourage decision-making, which is influenced by students' personal and moral considerations (Sadler & Zeidler, 2005).

The role of well-considered pedagogies in SSI science education is critical for the optimal development of the aforementioned abilities. According to Zeidler et al. (2005), four areas are of pedagogical importance, namely: nature of science issues, classroom discourse issues, cultural issues and case-based issues. The latter two aspects in particular refer to morality aspects. In case-based issues, the emphasis is on the moral aspect of SSI, in which the students become aware of the moral nature of the issue in question. This aspect encourages students' moral reasoning. With regard to cultural issues, the importance of mutual respect during discourse is emphasised and the students become aware of the fact that their moral judgements are influenced by their normative values, as well as their cultural beliefs about the natural world (Zeidler et al., 2005). Other researchers also argue that although scientific facts are indispensable in SSI argumentation, given that students' argumentation is often value-based, it is important to enable them to reflect on those values and on those of others, in relation to science (Gough, 2002; Grace & Ratcliffe, 2002; Oulton et al., 2004; Zeidler et al., 2005).

Additionally, with regard to SSI pedagogy, researchers argue that students should be given an opportunity to engage in debate and discussion in which argumentation naturally plays an important role (e.g., Hacker & Rowe, 1997; Driver et al., 2000). Various studies have demonstrated that peer group discussions contribute to students' knowledge base and to their awareness of values regarding SSI (Grace, 2009; Ratcliffe, 1997). According to Duschl and Osborne (2002), the absence of dialogical argumentation can even limit the learning process in science education.

SSI teaching and learning also encourage students to adopt multiple perspectives in order to make informed decisions. Empirical research has demonstrated the importance of learning to argue from different perspectives in order to come to a decision (Patronis et al., 1999; Wu & Tsai, 2007; Zeidler et al., 2003, 2009), that students learn to analyse scientific and normative evidence (Zeidler et al., 2009), and to take different values into consideration (Grace, 2009; Lee, 2007).

Given the focus on students' morality in this review study, we maintain that it resonates well with recent trends in socioscientific issues research, as discussed by Zeidler et al. (2019). These trends are conceptualised under the heading of 'science-in-context', in which research is conducted on the relationship between SSI and socioscientific reasoning, socioscientific perspective-taking and the importance of informal and place-based contexts. In doing so, the authors stress the importance of interdisciplinary research (cf. Bencze et al., 2020), of which this review study is an example.

The above research results demonstrate the promising potential benefits of teaching and learning SSI within science education. However, paying sufficient attention to the moral aspects of SSI within science education practice can often be challenging (cf. Hodson, 2013). According to R. Levinson and Reiss (2003), some science teachers believe that they should not deal with ethical and moral issues, since science is about explaining the natural world, while ethics is about how we should act. In a similar line of argument, Grace (2009) reports that SSI are often presented within science education as 'atomistic, value-free and as part of unconnected science curriculum topics' (p. 552), while according to Van der Zande et al. (2009), SSI are often used simply as a context in which to learn scientific concepts, with the moral reasoning regarding these issues being omitted. A perceived lack of lesson time is another important limitation for SSI teaching and learning (Kinskey & Zeidler, 2020; Oulton et al., 2004).

Another set of studies demonstrated that science teachers are generally unfamiliar or uncomfortable with teaching SSI (Day & Bryce, 2011; cf. Kinskey & Zeidler, 2020). An important reason for this is that they cannot rely on scientific knowledge alone and they may be afraid of being unable to deal with students' reactions (Berne, 2014; L. Simonneaux, 2013).

Other researchers argue that teachers not only find it difficult to organise classroom discussions (R.,& Levinson & Turner, 2001) and small group discussions on SSI (Bennett et al., 2010), but also need support on how to strengthen student argumentation (V. M. Dawson & Venville, 2010). Similarly, students often have difficulties understanding what is expected of them in group discussions (Lindahl et al., 2019). Following a study in which students used ethical frameworks relating to climate change, Reiss (2008) adds that both students and teachers needed support in their ethical reasoning regarding such dilemmas.

With a view to typifying SSI teaching and learning, Bencze et al. (2012) refer to Hodson (2003), who classified SSI science education into different 'levels of sophistication': a) appreciating the societal impact of scientific and technological change, and recognising that science and technology are, to some extent, culturally determined; b) recognising that decisions about scientific and technological development are taken in pursuit of particular interests, and that benefits for some may come at the expense of others – recognising that scientific and technological development are inextricably linked to the distribution of wealth and power; c) developing one's own views and establishing one's own underlying value positions; and d) preparing for and taking action (Hodson, 2003, p. 655). According to Bencze et al. (2012) levels a–c are often central to SSI science education, while attention to preparing for and taking action (level d) is often lacking. Given the seriousness of current environmental problems, the authors argue, we need activist-oriented societies to address the problems in order to achieve social and environmental sustainability (cf. dos Santos, 2009; Hodson, 2003). According to Hodson (2003), such societies have 'people who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere' (p. 660).

Purpose and research questions

In the preceding sections, we have attempted to illustrate the importance of paying attention to morality within science education. However, the science education literature shows that there are multiple barriers and challenges to paying sufficient attention to morality within science education that is embedded in SSI (Bencze et al., 2012; Bennett et al., 2010; Berne, 2014; Day & Bryce, 2011; Grace, 2009; R. Levinson & Reiss, 2003; V. M. Dawson & Venville, 2010; Oulton et al., 2004; R.,& Levinson & Turner, 2001; Reiss, 2008; L. Simonneaux, 2013; Van der Zande et al., 2009). All these challenges have been described in the context of secondary science education. There also appears to be less literature that deals with aspects of morality in primary and tertiary science education. This is illustrated by the yield for our search strategy, which is described in the Methods section below. This yield consisted of five empirical studies dealing with morality aspects within primary science education, and thirteen studies on such issues within tertiary science education. We therefore decided to focus our research on secondary science education.

This brings us to the purpose of this review study. Our study aims to explore empirical studies that emphasise aspects of morality in SSI in secondary science education. The following interrelated research questions guided the review:

(1) How is 'morality' conceptualised in SSI in secondary science education?
(2) How can such morality be guided and encouraged in SSI in secondary science education?

In order to answer these questions, we searched for empirical SSI studies in secondary science education that focused on aspects of morality. We describe our search strategy in the Methods section, where we also elaborate on our framework of analysis, the 'Four Component Model of Morality' (Narvaez & Rest, 1995; Rest et al., 1999), and describe how we used it to analyse our reviews of the papers.

Methods

This review study investigates what empirical studies have been conducted on morality within the context of secondary SSI science education. The literature search was limited to the present century (2000–2019). According to Zeidler (2014), references to SSI can be found in the literature as far back as the 1980s, when science-technology-society (STS) and science-technology-society-environment (STSE) approaches emphasised the importance of linking science to matters of social importance. However, considering that 'in recent years SSI have emerged as an educational construct' (Zeidler, 2014, p. 697), with a greater emphasis on considering the 'ethical dimensions of science, the moral reasoning of the child, and the emotional development of the student' (Zeidler, Walker, Ackett, & Simmons, 2002, p. 344), we considered it justifiable to limit our search to SSI studies with a focus on morality, published in the specified timeframe.

We used ERIC (Educational Resources Information Center) as the database for our study because it is known for its complete indexing system for educational research. With a view to guarantee the quality of the reviewed studies, we only included peer-reviewed

publications in our analysis. Table 1 summarises the specific search terms relating to morality in their different Boolean combinations and the number of studies yielded by each search action.

A number of subsequent actions were carried out to better align the sample with the focus of this study:

(a) Doubles were excluded;
(b) Only empirical studies in the 2000–2019 timeframe were included;
(c) Only studies in secondary science education were included;
(d) Only studies focusing on teaching and learning aspects of morality were included.

This resulted in 28 studies that met the criteria for further analysis. The outcome of this search strategy yielded a number of studies that investigated aspects of students' morality in different contexts, i.e. different from studies in which students addressed topics situated in the context of human nature (e.g., medical-ethical or biotechnological topics – cf. Tables 2–5). We are aware that morality and moral reasoning are context-dependent (cf. J. R. Rest et al., 2000); however, given the fact that these 'other studies' also focus on morality aspects within secondary science education, we believe that including them has an added value.

The Findings section below includes a number of tables in which the various studies are characterised in terms of their aims, context, topics and participants.

Analytical framework: Four Component Model of Morality

We used the Four Component Model (FCM) of Morality (Narvaez & Rest, 1995; Rest et al., 1999) to analyse the selected studies that focused on aspects of morality. Since the model is quite central to our review, we first elaborate on its background and components.

Extensive psychological research has shown that moral reasoning, which emphasises reflection on abstract moral principles (Narvaez & Rest, 1995; Rest et al., 1999), only partially determines moral behaviour. Developmental psychology has shown that other psychological processes also contribute to moral behaviour. This knowledge has helped in the development of the FCM of Morality, which assumes that four psychological processes affect one's moral behaviour (Narvaez & Rest, 1995; Rest et al., 1999):

(a) 'Moral sensitivity' involves the ability to interpret the reactions and feelings of others. It involves being aware of alternative courses of action, knowing cause-effect chains of events in the environment and how each could affect the parties concerned.
(b) 'Moral reasoning and judgment' refers to the ability to reason about what ought to be done in a specific situation.
(c) 'Moral motivation' acknowledges that individuals have legitimate concerns that may not be compatible with the moral choice. This component is also referred to as 'moral integrity'.

Table 1. Number of studies as a result of different search terms in ERIC (*first hits*).

Search item ('All text')	'AND' #	Socioscientific Issues/ Socio-scientific Issues ('All text')*
Moral Development		2
Moral Education		3
Moral Reasoning		13
Moral judgment		1
Moral Dilemmas		10
Moral Values		17
Morality		10
Ethics		38
Ethical Thinking		2
Ethical Decision-making		3
Values		88
Values Education		5
Values Clarification		1
Moral Behaviour		0
Behaviour		20
Moral Action		0
Action		40
Moral Character		0
Character		5
Total:		**258**

#*Search mode: Boolean/Phrase*

**Total yield (e.g., 'Moral Development' was entered as a search term with 'socio-scientific issues' and 'socioscientific issues' separately, which in total yielded 2 papers.*

(d) 'Moral character' attends to the importance of character in effective and responsible practice. This component is also referred to as 'ethical implementation' or 'moral action'.

The four processes are both cognitive and affective in nature; they depend on each other in often-different relationships. For example, the ability to recognise the moral aspects of a situation ('moral sensitivity') is related to one's 'moral motivation' and 'ethical implementation'; in other words, if someone recognises an issue as not being morally urgent, they will be less 'morally motivated' to perform a certain 'moral action' (Rest et al., 1986).

Analysis

The 28 studies were analysed as described below. After reading the articles, the first author wrote a review of each study. These reviews included the following characteristics of the studies: their purpose, theoretical framework, context (e.g., country, topics), data collection tools, data analysis, main findings and how the findings related to one or more aspects of morality. In order to establish how morality was conceptualised in the various studies and what pedagogies were applied, the focus was on mapping how, and to what extent, the various studies emphasised one or more components of morality. The papers and written reviews were read by the other authors. If they arrived at different conclusions

Table 2. Main Characteristics of Studies within the Context of Moral Sensitivity (FCM-1).

ID	Title	Author(s)	Year	Description
FCM-1.1	Moral Sensitivity in the Context of Socioscientific Issues in High School Science Students	Fowler, Zeidler, and Sadler	2009	American study aimed at investigating the extent to which an SSI-curriculum (within the context of biotechnology) contributes to the moral sensitivity development of 16- to 18-year old high school biology students.
FCM-1.2	Developing High Quality Decision-Making Discussions About Biological Conservation in a Normal Classroom Setting	Grace	2009	English study aimed at investigating the influence of a decision-making framework on 15- to 16-year old biology students' personal reasoning about a conservation issue, and what characterises high quality discussions.
FCM-1.3	Raising awareness of pre-symptomatic genetic testing	Boerwinkel, Knippels, and Waarlo	2011	Dutch study aimed at investigating the influence of using videos of real-life cases on 16-year old biology students' consideration of different views on this topic, and their argumentation in the context of genetic testing.
FCM-1.4	Climate Change and Morality: Students' perspectives on the individual and society	Sternäng and Lundholm	2011	Swedish study aimed at investigating how 14-year old Chinese students approached actions against climate change from a moral perspective.

(*Continued*)

about the studies' conceptualisations of morality and the pedagogies they applied, the reviews were discussed during team meetings until consensus was reached.

In order to address the first research question ('How is "morality" conceptualized within the context of addressing SSI in secondary science education?'), we compiled a synthesis describing the various studies' conceptualisations of the morality components, the emphases that were made, and how the studies related to each other (within the context of a specific FCM component).

To address the second research question ('How can such morality be guided and encouraged in SSI in secondary science education?'), we described the results of the various studies, then compared them in terms of understanding the factors influencing students' morality. We made this comparison within the context of the specific FCM components.

Limitations

This review is limited by various factors. First, it only focuses on empirical studies in science education. There will undoubtedly also be empirical research on morality within the humanities, which could be of great value for science education. The same applies to theoretical studies, which often reveal valuable insights.

In addition, no studies in primary or higher education were considered; their findings may also have been of value. We only looked at studies that focused on formal science education, thereby excluding studies focusing on non-formal science education, which may have provided valuable insights.

Only studies containing the search terms listed in Table 1 were included, although other studies that did not explicitly use those terms might also be conceptually related to morality, such as studies focusing on informal and socio-scientific reasoning. Furthermore, we realise that 'morality' is, in reality, even more complex and multidimensional (see e.g., Berkowitz, 1997; D.L. Zeidler & Keefer, 2003), which means that the search terms based on the FCM of Morality are not entirely comprehensive.

We limited ourselves to studies conducted since the turn of the millennium, although it is quite conceivable that older studies could still contribute valuable insights into this topic.

Only studies reported in English were included. We left out studies documented in other languages, which also make a valuable contribution to a (context-specific) knowledge base for guiding and encouraging morality aspects within secondary science education (e.g., Dittmer et al., 2016, published in a German-language journal; J. Simonneaux, 2007, published in a French-language journal).

This review is also limited by the fact that we only included studies published in academic journals, thereby ignoring potentially important contributions from other sources, such as doctoral dissertations, conference presentations and book chapters.

We used the FCM to categorise and describe the 28 papers, which provided an overview of the morality aspects central to the studies in these papers. However, this categorisation could not prevent some overlap of papers across different FCM components. The main reason for this overlap is that often, the studies did not focus primarily on one particular FCM component. For the studies to which this caveat applies, we explain why they have been assigned to the specific component.

The information provided on the studies is limited. For example, we do not provide much information about theoretical frameworks and the instruments used. This is because, in order to address our research questions, we wanted to confine ourselves to the essence of the various studies, i.e. the results for specific components of morality.

Despite the above-mentioned limitations, we believe that the 28 selected papers constitute a representative body of knowledge that can provide key insights into our research questions. To verify this, we compared the literature cited in the 28 papers: its comprehensiveness and mutual overlap have reinforced our belief that our assumption was correct.

Findings

In presenting the findings we use the four FCM components, where FCM-1 refers to ethical sensitivity, FCM-2 to moral reasoning and judgment, FCM-3 to moral motivation and FCM-4 to moral character. We start each section with a table showing which of the 28 reviewed articles relate to the FCM that is presented. Each article has its own code, which they are referred to by throughout the remainder of the paper. The tables can be used as a reference to the source, while the bibliography provides the full references. Within each morality component, we first present the findings in relation to the conceptualisation of morality, followed by the findings in relation to the factors influencing students' morality.

Empirical studies relating to 'ethical sensitivity' (FCM-1)

Central to the ethical sensitivity component of the FCM is the degree of sensitivity with respect to particular SSI. This component is referred to as 'moral sensitivity' (Narvaez & Rest, 1995; Rest et al., 1999; Bebeau, 2002). This means that the moral person senses that the SSI in question is a moral issue. It includes the ability to imagine cause-effect chains of events, as well as interpreting the situation and adopting a perspective in order to determine how various actions would affect the parties concerned. This suggests that the moral person is able to interpret and anticipate the reactions and feelings of others.

Based on our analysis, we have grouped six studies within this FCM component. Their main characteristics are summarised in Table 2.

Findings relating to the conceptualisation of moral sensitivity

In this section, we will summarise how the six studies help to advance the conceptualisation of ethical sensitivity in secondary science education.

FCM-1.1 shows that students' ethical sensitivity was influenced by the extent to which a topic was emotionally charged. This finding suggests that it is critical to focus on SSI that students feel emotionally affected by, or to at least to create a pedagogical space that enables students to connect to particular SSI. With regard to engaging students in sustainability-related issues, FCM-1.5 demonstrated that students tend to have a high degree of concern for the consequences of environmental damage to the biosphere. The author noted that this finding suggests that the students had a strong emotional connection to the biosphere, which positively influenced their moral reasoning within that context. This connection was even stronger than the one with 'self', 'family' and 'all other

Table 2. (Continued).

ID	Title	Author(s)	Year	Description
FCM-1.5	Secondary School Students' Environmental Concerns and Attitudes towards Forest Ecosystem Services: Implications for Biodiversity Education	Torkar	2016	Slovenian study aimed at investigating 15–16-year-old general upper secondary high school students' environmental concerns and attitudes towards forest ecosystem services.
FCM-1.6	Students' reasoning processes in making decisions about an authentic, local socio-scientific issue: bat conservation	Lee and Grace	2010	Chinese study aimed at investigating 15–16-year old biology students' personal values before and after an intervention on the conservation of biodiversity.

people'. In a similar context, FCM-1.4 found that students' conceptualisation of 'self' influenced how they related to the biosphere and how they felt responsible for resolving runaway climate change. In this study, students reported that this responsibility mainly lies with people other than themselves, which suggests moral sensitivity does not necessarily correlate with moral responsibility and action.

FCM-1.2, FCM-1.3 and FCM-1.6 placed greater emphasis on creating and enabling an environment for changing perspectives on complex moral issues. FCM-1.3 showed that the use of videos depicting real-life interviews with multiple stakeholders holding different values helped improve students' understanding (awareness) of the complexity of a topic. FCM-1.2 and FCM-1.6 developed a decision-making framework that proved effective in increasing students' abilities in adopting different perspectives on certain topics. When taking a position on the issue in question, students showed greater awareness of the different values involved (FCM-1.2). In FCM-1.6, the use of the framework even showed that some students shifted away from predominantly anthropocentric values towards more inclusive biocentric values in relation to the topic.

In summary, the following aspects were central to the conceptualisation of students' moral sensitivity: how the students related to the issue, their perspectives on the 'self' in relation to the issue and their emotional involvement (their concern) with the issue. Students' awareness of the topic's complexity was also central to some studies, which was evidenced by their skill in taking different perspectives on the associated values.

Factors influencing students' moral sensitivity

The six FCM-1 studies (Table 2) provide specific insights into the factors influencing students' moral sensitivity. FCM-1.1 showed that both the content and context are determining factors in this regard. In a scenario where students focused on the genetic modification of organisms (GMOs), more knowledge was required to help understand the moral underpinnings of GMOs. A scenario focusing on reproductive cloning, on the other hand, was emotionally charged from the outset due to the context in which it was set, which made the students sense the scenario's moral dimension at an early stage. The study found that both scenarios ultimately made a more or less equal contribution to the development of students' moral sensitivity.

Both FCM-1.2 and FCM-1.6 used interventions that required students to discuss an issue using a decision-making framework. In FCM-1.2, this resulted in a greater awareness of the values involved in the issue. The study also showed that the quality of the dialogue between the students positively influenced their reasoning. Similarly, the results of FCM-1.6 showed that applying a decision-making framework, combined with small group discussions, increased students' awareness of the values involved in the issues in question. In particular, the students became aware of, and more sensitive to, biocentric values that they were unfamiliar with prior to the intervention. According to the researchers, this awareness and shift away from more mainstream anthropocentric values was partly the result of an increase in students' knowledge about the crucial role of bats in maintaining a healthy ecosystem.

FCM-1.3 also experimented with a specific pedagogical approach in the context of genetic testing, where students had to pose their own questions. The question-posing approach resulted in an increased awareness of the complexity of the issue as students came to realise that different groups in society have different interests, that the

information about genetics is in flux and uncertain, and that pre-symptomatic genetic testing often involves conflicting values.

The results of FCM-1.4 showed that the conceptualisation of the 'self' influenced how students positioned themselves morally in relation to resolving runaway climate change. Here, assessment of the level of sacrifice required to help mediate a complex issue seemed to negatively influence both the perception of the seriousness of the issue and one's inclination to feel responsible and to act.

Finally, the results from FCM-1.5 showed that, within the context of environmental concerns for the consequences of environmental damage, students' concerns were greatest for the negative impact of human behaviour on the biosphere. These concerns were greater than 'egoistic concerns' (for self and family) and 'altruistic concerns' (for all people), which suggests that the students involved in this study were morally sensitive to SSI within a human-nature context.

In summary, students' moral sensitivity was influenced by the following factors: the topic's content and context (the extent to which the topic is emotionally charged); and pedagogy (e.g., group dialogue and using a decision-making framework that helps create an awareness of the values involved). Also, students' assessment of the 'level of sacrifice' regarding the issue seemed to negatively influence both the perception of the seriousness of the issue and their inclination to feel responsible and to act.

Empirical studies relating to 'moral reasoning and judgment' (FCM-2)

The moral reasoning and judgment component of the FCM refers to proposed actions that are justifiable in a moral sense (Rest et al., 1999). Central to this component is the question, 'what am I supposed to do?' (Rest, 1984). Reiss (2008) argued that there is no single, undisputed, generally accepted way of deciding whether a decision or an action is morally acceptable or not, since there are different ethical frameworks. Within each of these frameworks it is possible to decide whether a specific action is right or wrong, taking the framework's moral principles as a starting point (Reiss, 2008). These decisions are often based on their consequences (teleological reasoning) or moral principles (deontological reasoning).

Reasoning with the help of these frameworks is largely a rational process. However, Sadler and Zeidler (2005) examined post-secondary students' patterns of informal reasoning and the role of morality in these processes. According to the researchers, informal reasoning includes both cognitive and affective processes, which contribute to the resolution of SSI. They argued that SSI are open-ended, ill-structured, debatable problems, and they used the term 'informal reasoning' to describe how individuals negotiate and resolve them. The researchers explicitly referred to SSI as moral issues. Their study therefore focused on students' informal reasoning in the context of SSI, with a specific focus on students' morality. It appeared that students demonstrate rationalistic, emotive and intuitive forms of informal reasoning. Sadler and Zeidler refer to rationalistic informal reasoning when the students' considerations are reason-based, emotive informal reasoning when they are care-based, and intuitive reasoning when they are based on immediate reactions to the context of a scenario. It appeared that the students often rely on combinations of these reasoning patterns. In line with these results, we also found when interpreting this morality component in the reviewed studies, that both cognitive

and affective forms of moral reasoning occurred (cf. Sadler & Zeidler, 2005). Based on our analysis, we have grouped seven studies within this FCM component. Their main characteristics are summarised in Table 3.

Findings relating to the conceptualisation of moral reasoning and judgment

In this section, we present the insights from these seven studies into the conceptualisation of this FCM-component within secondary science education.

FCM-2.1 presented moral reasoning as a mainly cognitive activity in that the researchers found a correlation between students' learning achievements and their analytical thinking in the context of SSI. This cognitive aspect also showed up in FCM-2.3, where the researchers found a correlation between students' knowledge and their ethical decision-making. In FCM-2.6, the cognitive aspect also played an important role since it focused on students' ability to utilise scientific concepts and ethical frameworks, which were used as indicators of the progression of their moral reasoning.

The conceptualisation of moral reasoning in FCM-2.4 contains both cognitive and affective aspects. In it, no specific intervention for developing students' moral reasoning was used. Rather, students were exposed to the moral aspects of different scenarios, after which they filled in an inventory which provided an overview of the moral values they considered most important in relation to a particular dilemma. This lesson activity calls on both the students' analytical skills (a cognitive activity) and their ability to weigh which moral value is most important (an activity that appeals to both their cognitive and affective skills).

FCM-2.2 used SSI only as a context for investigating students' moral reasoning. Unlike the studies referred to so far, this study suggested not only that students barely applied moral principles in their arguments, but also that there was no connection between moral reasoning, content knowledge and the quality of their arguments. However, the students did express moral considerations in relation to the topic, but these were grounded more in emotions than in rational thinking. This finding suggests a need for a broader conceptualisation of moral reasoning that allows for both the rational and the affective application of moral principles. Such a broad conceptualisation is provided in FCM-2.5, which focused on the quality of students' moral reasoning. This quality is determined by the number of justifications students applied in their reasoning. The authors argue that these justifications can also be based on emotions, which they consider perfectly legitimate. However, they did find that students with less content knowledge relied more frequently on intuitive moral reasoning.

In summary, consistent with the findings of Sadler and Zeidler (2005), students' moral reasoning and judgment can be conceptualised as both a cognitive and an affective activity. In the studies in which moral reasoning and judgement was mainly conceptualised as a cognitive activity, a correlation was oftentimes found between the (ability of applying) scientific knowledge and the use of ethical frameworks, or ethical decision-making. In the studies in which moral reasoning was mainly conceptualised as an affective activity, it appeared that students' justifications in their moral argumentation were often based on their emotions.

Factors influencing students' moral reasoning and judgment

Studies FCM-2.2, 2.4 and 2.5 focused on the articulation of this particular FCM component. FCM-2.2 revealed, for example, that there was no correlation between students' content

Table 3. Main Characteristics of Studies within the Context of Moral Reasoning and judgment (FCM-2).

ID	Title	Author(s)	Year	Description
FCM-2.1	Learning outcomes between Socioscientific Issues-Based Learning and Conventional Learning Activities	Wongsri and Nuangchalerm	2010	Thai study aimed at investigating the effects of SSIs-based instruction on 12–13-year old students' learning achievements, analytical thinking and their moral reasoning (context: *presumably* climate change – the article is not entirely clear about this).
FCM-2.2	Socioscientific Argumentation: The effects of content knowledge and morality	Sadler and Donnelly	2006	American study aimed at investigating how moral reasoning and content knowledge contribute to the quality of 15–18-year old biology students' argumentation within the context of genetic engineering.
FCM-2.3	A Pedagogical Model for Ethical Inquiry into Socioscientific Issues In Science	Saunders and Rennie	2013	New Zealand study aimed the development of a pedagogical framework for 13–18-year old secondary science students, in order to stimulate the process of ethical inquiry (context: global warming, euthanasia, prenatal genetic screening, and in vitro fertilisation).
FCM-2.4	Determination of Bioethical Perceptions of Gifted Students	Ceylan and Topsakal		

(*Continued*)

Table 3. (Continued).

ID	Title	Author(s)	Year	Description
2018	Turkish study aimed at investigating the distribution of 10–15-year old gifted students' moral values, and different background variables influencing their decisions and moral values (context: euthanasia, organ donation, GMO products, and embryology technologies).			
FCM-	2.5	Is judgment of Biotechnological Ethical Aspects Related to High School Students' Knowledge?	Črne-	Hladnik, Hladnik, Javornik, Košmelj, and Peklaj
2012	Slovenian study aimed at investigating 17-year old biology students' moral reasoning and the relationships among their pre-knowledge of genetics, and their attitudes to different biotechnological applications.			
FCM-	2.6	Progression in Ethical Reasoning When Addressing Socio-scientific Issues in Biotechnology	Berne	2014
	Swedish study aimed at investigating the factors that indicate 14–15-year old students' progression in ethical reasoning, and the link between the quality of group discussions and students' progress in ethical reasoning (context: cloning and designer babies).			
FCM-	2.7	Improving students' argumentation skills through a product life-cycle analysis project in chemistry education	Juntunen	and Aksela
2014	Finnish study aimed at investigating 15-year-old Finnish secondary chemistry students' ethical argumentation within the context of the life-cycle analysis of products.			

knowledge, their moral reasoning and their argumentation quality. The study also showed that students frequently used moral considerations in their reasoning but neglected the strict application of moral principles. According to the researchers, this is an argument for providing students with more time and space for emotions.

Study FCM-2.4, which was set in the context of students' deliberations around the use of GMO seeds, found that students' moral reasoning was of a teleological nature. This teleological form of reasoning was also found in FCM-2.5, where students used deontological reasoning as well. Both forms of reasoning can be qualified as 'rational.' Students with very little knowledge of genetics tended to reason more intuitively in FCM-2.5. In other words, a correlation was found between the level of knowledge and both the quality and the type of moral reasoning. Similar results were obtained in FCM-2.1 (correlation between learning achievements and moral reasoning), FCM-2.3 (correlation between increase in scientific knowledge and students' ethical decision-making) and FCM-2.6 (using scientific concepts in argumentation, and approaching the issue from multiple ethical frameworks). For these studies too, a correlation was found between knowledge, or knowledge increase, and both the quality and nature of moral reasoning.

However, the other studies on this FCM did not find any correlations between student knowledge and moral reasoning. For example, no correlation was found in FCM-2.2 between students' content knowledge, their moral reasoning and argumentation quality. FCM-2.7 concluded that while students' scientific and ecological argumentation skills improved, their 'ethical argumentation' skills lagged behind.

The studies reported in FCM-2.1, FCM-2.3, FCM-2.6 and FCM-2.7 provided insights into students' moral reasoning and the development of their judgment skills. For example, FCM-2.1 showed that an SSI-based curriculum can contribute positively to students' moral reasoning skills and that these are connected to their learning achievements, including their analytical thinking skills. Study FCM-2.3 revealed that the development of a pedagogical framework using several ethical heuristics enhanced their argumentation and decision-making efforts and ultimately helped improve the quality of their ethical decision-making. The latter was shown in the quality of the arguments supporting their decisions and in their ability to reason within the different ethical perspectives provided by the framework. In addition, they were better able to approach an SSI from a perspective different from their own.

In FCM-2.6, the researchers focused on the quality of group discussions. The study found that students' progression in ethical reasoning was related to the type of interactions that took place in the peer discussions: students who argued critically and constructively about each other's ideas, and challenged each other's claims, made progress in more aspects of ethical reasoning than students who simply used cumulative talk. Progress in the quality of ethical reasoning was indicated by an increased utilisation of scientific concepts and ethical frameworks.

Finally, study FCM-2.7 showed that while the context of an SSI – in this case the life-cycle analysis of products – could help improve students' scientific and ecological argumentation skills, it did not appear to influence their ability to construct ethical arguments. The researchers attributed this to the cultural context in which the study took place – namely, Finland, where the researchers report that students are less accustomed or willing to share their moral views in groups.

Table 4. Main Characteristics of Studies within the Context of Moral Motivation (FCM-3).

ID	Title	Author(s)	Year	Description
FCM-3.1	Using the SEE-SEP Model to Analyse Upper Secondary Students' Use of Supporting Reasons in Arguing Socioscientific Issues	Christenson, Chang-Rundgren, and Höglund	2012	Swedish study aimed at investigating the use of 18–19-year old science and social science students' supporting reasons in their argumentation, and to what extent they used scientific knowledge in their argumentation (context: global warming, GMOs, nuclear power and consumer consumption).
FCM-3.2	The Relationship of Discipline Background to Upper Secondary Students' Argumentation on Socioscientific Issues	Christenson, Chang-Rundgren, and Zeidler	2014	Swedish study aimed at investigating the difference between 18–19-year old social science and science students with regard to the kind of supporting reasons they used in their argumentation (context: global warming, GMOs, nuclear power or consumer consumption).
FCM-3.3	Students' Perception of Risk About Nanotechnology After an SAQ Teaching Strategy	Simonneaux, Panissal and Brossais	2013	French study aimed at investigating 17–19-year old science students' interactions during a debate on nanotechnology. The researchers also investigated students' risk perceptions with regard to nanotechnology.
FCM-3.4	Investigating the Intertwinement of Knowledge, Value, and Experience of Upper Secondary Students' Argumentation Concerning Socioscientific Issues	Rundgren, Eriksson, and Chang-Rundgren	2016	Swedish study aimed at investigating the influence of 17–19-year old science students' 'intellectual baggage' (i.e., their prior knowledge, values, and past experiences) on their SSI argumentation within the context of the consumption of dioxin contaminated fatty fish from the Baltic Sea.
FCM-3.5	'Thank You for Being Republican': Negotiating Science and Political Identities in Climate Change Learning	Walsh and Tsurusaki	2018	American study aimed at investigating the influence of 14–15 year old biology students' conflicting identities (e.g., their identity from home and their school-based insights) on their participation in a curriculum within the context of human-induced climate change (HICC).
FCM-3.6	Opinion building on a socio-scientific issue: the case of genetically modified plants	Ekborg	2008	Swedish study aimed at investigating which knowledge and values are important for upper secondary biology students to form their opinion with regard to genetically modified plants.
FCM-3.7	Patterns in Students' Argumentation Confronted with a Risk-focused Socio-scientific Issue	Kolstø	2006	Norwegian study aimed at investigating the kind of arguments that were crucial for science students' decisions with regard to powerlines and the possible increased risk of childhood leukaemia.
FCM-3.8	The Influence of Global Warming Science Views and Sociocultural Factors on Willingness to Mitigate Global Warming	Herman	2015	American study aimed at investigating the correlation between 14–19-year old marine science students' perceptions about global warming (GW), their perceptions about the nature of GW science and their socio-cultural background, and the extent to which they were willing to show behaviour that mitigates GW.
FCM-3.9	Threat Perception and Attitudes of Adolescents Towards Re-Introduced Wild Animals: A qualitative study of young learners from affected regions in Germany	Hermann and Menzel	2013	German study aimed at investigating 14–19-year old students' attitudes with regard to the reintroduction of wolf and bison in Germany. The researchers also explored how the students' estimate wildlife threats, and their knowledge of endangered species in Germany.

(*Continued*)

Table 4. (Continued).

ID	Title	Author(s)	Year	Description
FCM-3.10	Integrating Socio-Scientific Issues to Enhance the Bioethical Decision-Making Skills of High School Students	Gutierez	2015	Filipino study aimed at investigating the influence of an SSI curriculum on 13–14-year old biology students' bioethical decision-making skills (context: biotechnology, environmental degradation, and cancer research).
FCM-3.11	Developing Students' Futures Thinking in Science Education	Jones, Buntting, Hipkins, McKim, Conner, and Saunders	2012	New Zealand study aimed at investigating 'futures thinking' as a pedagogical approach for teaching science to 8–16 year old students (context 16-year olds: future possibilities for genetically modified foods).

In summary, the studies demonstrate the importance of helping students to reflect upon their (emotional) relationship to the topic, which can positively influence the process of moral reasoning and judgment (FCM-2). There were varying correlations between students' content knowledge and the quality of their moral reasoning: while some studies showed a positive correlation, this correlation was absent in other studies. The studies' conceptualisation and evaluation of this FCM component were probably responsible for this result. Other factors that influenced students' moral reasoning and judgment skill were the studies' central pedagogies (e.g., using a framework with several ethical heuristics, stimulating group discussions). With regard to the latter, the quality of the interaction during group discussions appeared to influence the quality of students' moral reasoning and judgment.

Empirical studies relating to 'moral motivation' (FCM-3)

The question 'What would I do?' is central to the 'moral motivation' component of the FCM (Habermas, 1983, p. 195). While the emphasis in 'moral reasoning and judgment' is on judging which action would be most justifiable in a moral sense, 'moral motivation' is concerned with evaluating the degree of commitment to taking the moral course of action, valuing moral values above other values (e.g., certain cultural values, egoistic interests, (group) solidarity), and taking personal responsibility for moral outcomes (Rest et al., 1999). This component is also called the 'judicial aspect of morality' (Korthals, 1986) and acknowledges that the moral agent may have legitimate concerns that may not be compatible with the moral choice (Bebeau, 2002). However, due to varying degrees of ambiguity and contradiction between cultures and contexts, these concerns can even lead to emotional and cognitive conflicts (D.L. Zeidler & Keefer, 2003). According to psychologists, the moral agent requires 'ambiguity tolerance' as a character trait to be able to deal with this. On the one hand, this implies a fundamental choice for the moral good, from which other non-moral values are approached. On the other hand, it is also important to show 'benevolence' rather than rigidly adhering to well-founded but (often) abstract principles (Korthals, 1986).

Based on our analysis, we have grouped 11 studies within this FCM component. Their main characteristics are summarised in Table 4. These studies mainly investigated students' values and other factors that influenced their decision-making regarding SSI. 'Moral motivation' as such was not always explicitly investigated. However, the various studies do provide insights into the various factors that influenced students' moral motivation.

Findings relating to the conceptualisation of moral motivation

FCM-3.1 and FCM-3.2 showed that a minority of students appealed to 'knowledge' in their argumentation on the topic, while most students used 'values' as justifications. FCM-3.4, FCM-3.6 and FCM-3.7 showed that students' knowledge of the risks associated with the issue in question influenced their perceptions of the impact on health or the environment, which in turn influenced their arguments and decision-making. In addition, research in FCM-3.6 showed that knowledge, or rather a lack of knowledge, influenced which values weighed more heavily in students' deliberations. FCM-3.7 showed that students made little use of school-taught knowledge, but that the knowledge they did accumulate could be decisive in their argumentation and decision-making.

While students seemed to make limited use of scientific knowledge in moral reasoning, studies FCM-3.1, FCM-3.2, FCM-3.6, FCM-3.7, FCM-3.9 and FCM-3.10 indicated that students used values as a basis for justifying their argumentation and decisions regarding an SSI. Study FCM-3.7 even suggested that values were used as warrants, much in accordance with Toulmin's argumentation structure (Toulmin, 1958).

FCM-3.11 showed the importance of reflection on one's own personal values when students were investigating drivers and trends in SSI. FCM-3.9 also emphasised the importance of reflection on personal values alongside the evaluation of what the authors refer to as 'ecological facts'. FCM-3.4 even found that students who had no personal values with respect to an SSI could not arrive at a decision. Reflection on personal values was also emphasised in the context of climate change, in particular by asking students to think about their position within eco-social timescales (FCM-3.5). Finally, FCM-3.3 stressed the importance of reflecting on personal values as a way to assist students' judgment and decision-making in the context of nanotechnology use.

The various studies showed that taking part in an SSI curriculum that included debate and discussion contributed both to students' awareness of personal values (FCM-3.4, FCM-3.5, FCM-3,10, FCM-3.11) and to their recognition of the importance of becoming aware of their own values (FCM-3.3, FCM-3.6, FCM-3.7). Although FCM-3.1 and FCM-3.2 were not intervention studies, they did reveal the importance of becoming aware of one's own values. These two studies also pointed to the importance of working across disciplines so that SSI could be explored from different disciplinary vantage points. As these studies indicate, this helps to create a better understanding of the values at play and an increased awareness of one's own personal values and of how they can be incorporated in the deliberation and decision-making process.

With regard to the development of personal values within an SSI-based secondary science education curriculum, FCM-3.5 revealed that values were susceptible to change. That study found that students' participation in the discourse around climate change contributed to 'identity' conflicts, as students discovered that they had multiple identities that were not always well-aligned: the identity they received from home, their inherited political and scientific values, knowledge and beliefs, and their school-based knowledge about human-induced climate change. The researchers suggested that students' personal values potentially develop through this kind of learning, sometimes leading to 'a new, reconciled identity', which can include other personal values as well.

With regard to the kinds of values that students employ, some of the studies showed that the more personal context of the individual students determined which values weighed most heavily in their argumentation and decision-making. Study FCM-3.7, for example, showed that students primarily employed teleological values in their argumentation when judging the health risks of power lines. Study FCM-3.9 revealed that students adopted a moralising attitude when considering the return of wild animals, placing values such as justice and autonomy (i.e. deontological values) at the centre. The results of studies FCM-3.7 and FCM-3.9 are illustrative of values that stem from a more rational form of reasoning. However, the motivation for weighing certain values more heavily than others can arise from emotions. FCM-3.6 showed that when students could not think of any rational arguments for or against, they resorted to their feelings or emotions, which is illustrative of a more intuitive-emotional form of reasoning.

Finally, we refer to the results of FCM-3.8 and FCM-3.10, which showed that the extent to which students assumed that a personal sacrifice was needed influenced their motivation to display certain behaviour. FCM-3.8 concluded that when students assumed a high personal sacrifice, they were less willing to exhibit actions to mitigate global warming. This result is very much in line with earlier findings by Sternäng and Lundholm (2011), introduced in the section about FCM-1 (i.e. FCM-1.4), which indicated that the way in which students conceptualised the individual (i.e. 'student as self', or 'student as other') determined how they related to climate change, essentially placing responsibility for climate change on other people, not themselves.

The following section demonstrates the overlap between factors influencing moral motivation and its conceptualisation. In our analysis, we assume that these factors shed light on students' moral motivations, which contributes to the conceptualisation of the component. Regarding the conceptualisation of moral motivation, we conclude from the 11 studies that 'knowledge', or lack of knowledge, and (personal) 'values' form part of a person's motivation. With regard to personal values, various studies have shown the importance of reflecting on these values. This leads to a growing awareness of those values, which enhances the quality of the decision-making process. Finally, it emerged that the awareness of personal sacrifice in relation to an issue is also part of moral motivation.

Factors influencing students' moral motivation

As stated above, most of the studies introduced here added to our understanding of the resources students used in their argumentation and decision-making on specific issues. In almost all of the 11 studies within FCM-3 (except for studies FCM-3.3 and FCM-3.8), these resources mainly comprised 'values', although 'knowledge' was also used as a resource in some studies (FCM-3.1, FCM-3.2, FCM-3.4, FCM-3.5 and FCM-3.6). In addition, the level of risk associated with certain SSI also influenced students' argumentation and decision-making (FCM-3.3, FCM-3.6, FCM-3.7). FCM-3.3 showed that student's fundamental views on nanotechnology, which ranged from highly unfavourable to highly favourable, heavily influenced both their risk assessment and their argumentation. Similarly, risk assessment was a decisive factor in students' argumentation and decision-making in FCM-3.6 and FCM-3.7.

Since commitment is central to moral motivation (FCM-3), it is worthwhile knowing which factors were decisive in students' motivation and commitment. FCM-3.1, FCM-3.2, FCM-3.6, FCM-3.7 and FCM-3.9 revealed that 'values', more so than 'knowledge', were most commonly used in students' argumentation. In FCM-3.3, students' personal views (either 'optimistic' or 'pessimistic') were decisive. FCM-3.4 showed that a student with no personal values regarding the issue was unable to come to a decision. This illustrates the importance of having an 'emotional link' with the topic. This was also the case in FCM-3.1, in which the students with no relationship to the topic barely used their 'personal experience' as a resource in their argumentation.

FCM-3.4 demonstrated that students' decisions differed depending on their background knowledge, values and experiences (i.e. their 'intellectual baggage'). FCM-3.5 demonstrated that student participation in activities, both inside and outside the classroom, contributed to a 'reconciliation' of identities that were previously in conflict (e.g., conflicting political and scientific knowledge, values and identities). These findings

Table 5. Main Characteristics of Studies within the Context of Moral Character (FCM-4).

ID	Title	Author(s)	Year	Description
FCM-4.1	Students' environmental NOS views, compassion, intent, and action: Impact of place-based socioscientific issues instruction	Herman	2018	American study aimed at investigating the influence of place-based instruction on 12–17-year old science students' nature of science (NOS) views and their compassion towards humans and nature as well as the influence of these two factors on students' intentions and pro-environmental action (context: wolf reintroduction in Yellowstone National Park)
FCM-4.2	Towards citizenship science education: what students do to make the world a better place?	Vesterinen, Tolppanen, and Aksela	2016	Finnish study aimed at investigating 15–19-year old students' intentional and purposive actions within the context of sustainability, meaning actions which they themselves considered responsible in improving or preserving the world.
FCM-4.3	Activity and Action: Bridging Environmental Sciences and Environmental Education	Tal and Abramovitch	2013	Israeli study aimed at investigating an Environmental Workshop (EW) module for its suitability as a model for teaching environmental education to 16–17 year-old science students (context: use of natural resources, and road construction through a vulnerable nature area).
FCM-4.4	Students' Research-Informed Socio-scientific Activism: Re/Visions for a Sustainable Future	Bencze, Sperling, and Carter		Canadian study aimed at investigating the nature and extent 15–16-year old science students' self-directed research-informed activism on SSIs, and factors that influence such activism (context: sustainability).

showed the importance of (carefully) organised SSI education, which can be of decisive significance for primary properties, such as 'values' and 'identities'.

FCM-3.6 showed that the students' 'knowledge' about the risks of genetic modification affected their argumentation and decision-making. Their knowledge also affected which 'values' were most important to them. The influence of knowledge was also evident in FCM-3.7, which demonstrated that students' decisions regarding power lines and the possible increased risk of childhood leukaemia were mainly based on teleological values, which meant that 'cause and effect' were central to students' reasoning. Knowledge about the potential risks was revealed to have a decisive influence on their decisions. This was also evident from FCM-3.4, where some students indicated that they were willing to change their opinions if they knew more about the risks.

FCM-3.8 showed a relationship between sociocultural factors and assessing the reliability of global warming science claims on students' willingness to mitigate climate change. In cases where socio-cultural factors had a significant influence on actions to mitigate global warming, it emerged that the greater the personal sacrifice, the less the actual willingness (i.e. students' motivation) to mitigate global warming. Similarly, FCM-3.10 demonstrated that the issue's influence, or expected influence, on the students' personal life affected their decision-making.

A number of studies described the kind of values that students used in their argumentation and decision-making. As outlined above, the results of FCM-3.7 demonstrated that students often used teleological values in their argumentation and decision-making regarding the risks of power lines. FCM-3.9 dealt with another topic, namely the return of wolves and bison to Germany. That study showed that students often used deontological – and to a lesser extent teleological – values in their reasoning. The nature of the topic therefore appeared to influence the type of values that students appealed to in their reasoning, and which were of decisive influence in their decision-making.

Finally, a number of studies – FCM-3.3, FCM-3.5, FCM-3.6, FCM-3.7, FCM-3.9, FCM-3.10 and FCM-3.11 – showed the importance of reflecting on personal values. These values often had a decisive impact on students' argumentation and decision-making. These results illustrate the importance of situating SSI education in a context in which an emotional connection can be made with the topic.

In summary, 'values' – more so than 'knowledge' – were most commonly used in students' argumentation and decision-making. Other factors of influence were (well-organised) SSI pedagogy (e.g., group discussions, discourse, choosing topics that the students could relate to emotionally), which helped enhance awareness of personal values, or even prompted a 'change' or 'development' in students' values or identities. The issue's (expected) influence on the students' personal life also affected their decision-making. In addition, the nature of the topic influenced the kind of values (deontological or teleological) that the students appealed to in their reasoning.

Empirical studies relating to 'moral character' (FCM-4)

'Moral character' is central to this FCM component (Rest et al., 1999), meaning that the moral agent may or may not engage in certain moral behaviour. Moral character implies that the acting person has sufficient motivation, self-respect and self-confidence to attune their behaviour to the chosen standard. An influencing factor for the moral character is

'ego-control': the feeling that one can 'successfully' intervene (according to the chosen norm) in social reality (Rest, 1984).

Based on our analysis, we have grouped four studies within this FCM component. Their main characteristics are summarised in Table 5.

Findings relating to the conceptualisation of moral character

As with FCM-3, there is an overlap within this FCM component between conceptualisation and the influencing factors with regard to moral character. We assumed accordingly in our analysis that the factors influencing students' moral character also contribute to the conceptualisation of this component.

FCM-4.1, FCM-4.3 and FCM-4.4 were intervention studies. They all investigated factors that contributed to students' 'moral behaviour'. In FCM-4.1, 'action' was conceptualised as concrete action, namely whether or not students donated money to an environmental organisation. FCM-4.3 and FCM-4.4, on the other hand, focused on factors contributing to students' intentions based on 'commitment, responsibility, self-efficacy, and deep understanding of what to do' (FCM-4.3, p. 1674), or to their 'commitment to activism' (FCM-4.4). This shows their relationship with FCM-3 (moral motivation). However, since these studies focused on factors that influence moral behaviour, we have grouped them under FCM-4.

FCM-4.3 emphasised the importance of using various types of environmental knowledge (e.g., system, action-related and social knowledge) to promote students' moral behaviour in lesson programmes that were 'student-oriented', 'constructionist' and aimed at 'taking a stand'. FCM-4.4 showed that 'research-informed activism projects' – lesson programmes in which students conducted their own research – positively contributed to their motivation to act.

Similar factors were also found in FCM-4.1, which showed that 'compassion toward nature' and 'concern for people impacted by contentious environmental issues' influenced students' actions, i.e. donating money to an environmental organisation. The above illustrates the importance of carefully designed SSI pedagogy facilitates and encourages the above factors.

In FCM-4.2, which was not an intervention study, 'action' was conceptualised in broad terms. Within that study, students were interviewed about how they could help improve or conserve the world in the context of sustainability challenges. In the analysis, the researchers focused on the rationalisations of the actions described by the students. They found that the students described three types of actions: (a) personally responsible actions (acting responsibly towards the environment, such as recycling, or buying ecologically produced food); (b) participatory actions (organising or taking part in school and community efforts, such as cleaning nearby beaches); and (c) preparing for the future (such as learning to design sustainable technologies). These different types of behaviour could be taken into account when designing SSI science education within the context of sustainability. Education of this kind could encourage these types of behaviour.

In summary, the studies each contributed to the conceptualisation of moral character. One study focused on concrete moral behaviour (i.e. donating money), while the others focused on the degree of commitment to implementing moral behaviour. Both aspects are part of students' moral character. The studies also shed light on the underlying rationalisations about whether or not to display certain moral behaviour. Within these rationalisations, responsibility can lie primarily with the students themselves, or there may

be a 'shared responsibility' for implementing moral behaviour (e.g., addressing sustainability challenges).

Factors influencing students' moral character

The four studies have improved our understanding of the factors that influence students moral character, or moral behaviour. FCM-4.1 demonstrated that place-based instruction on the reintroduction of wolves to Yellowstone National Park (USA) had a positive influence on students' compassion towards people and nature in relation to the topic. There was also a significant increase in the proportion of students who gave specific examples of how they intended to help the environment. The researcher evaluated 'moral behaviour' in terms of students donating money to an environmental organisation. An important indicator for 'donating money' was a more accurate view of the associated nature of science (NOS), i.e. students' knowledge about theories, such as trophic cascade that can be revised, and how research conducted in the same areas can produce different results and conclusions. Another important indicator for 'donating money' was that the donating students demonstrated more compassion towards natural entities than non-donating students. These results demonstrate the importance of designing SSI science education that helps develop NOS skills, and encouraging an emotional connection with the topic.

FCM-4.3 was an intervention study in which students studied an environmental workshop (EW) module. The researchers concluded that students who combined multiple types of knowledge (i.e. system, action-related, effective and social knowledge) were more inclined to act morally. The study modules that were most 'student-oriented', 'constructionist' and focused on 'conflict' (i.e. 'involvement is a result of taking a stand') contributed mainly to the action-taking skills.

The latter aspect was also central to intervention study FCM-4.4, in which students developed and implemented research-informed socio-political actions to address socio-scientific issues. It appeared that the students' commitment to activism depended on a number of factors (i.e. concern, self-confidence, self-efficacy) that are central to an individual's 'moral character'. The programmes in which students conducted their own research contributed primarily to their motivation and, therefore, to their commitment to activism. This finding matches the results of FCM-4.3, in which the predominantly student-oriented approach contributed more effectively to students' motivation and their action-taking skills.

The findings of these intervention studies demonstrate the importance of carefully designed SSI science education. In this kind of education, the students are encouraged to reflect on their moral motivation, and to 'act' on that basis, or it at least offers them a perspective on opportunities for action.

FCM-4.2 was an interview study in which the researchers focused on students' rationalisations about their moral behaviour. The findings showed that the students' intentions and motivations for addressing sustainability problems were diverse and they described the behaviour needed to address these problems in many different ways. The results of this study also demonstrated the importance of creating time and space for the students to reflect on their personal values, which potentially increases their awareness of these values ('positive cognition'), offering them a perspective for action.

In summary, a well-considered pedagogy influences students' moral character and moral behaviour. According to the four studies, students are central within such a pedagogy because, for example, they carry out their own research. The pedagogy is constructionist and focused on 'taking a stand'. Students are encouraged to reflect upon their personal values. All this has a potential positive influence on students' moral character – involving their commitment, self-confidence and self-efficacy – and therefore on their moral behaviour.

Recommendations and implications

For the purpose of this review study, we analysed 28 empirical studies with a focus on morality in the context of SSI. The 'Four Component Model' (FCM) of Morality (Narvaez & Rest, 1995; Rest et al., 1999), derived from developmental psychological research, describes morality, which comprises the following psychological processes: moral sensitivity, moral reasoning and judgment, moral motivation and moral character (Narvaez & Rest, 1995; Rest et al., 1999). We used the FCM as an analytical framework to review the 28 studies in order to create a knowledge base for how morality has been conceptualised in science education and how it can be developed. In what follows, we discuss the implications of the analysis outcomes for theory, research, and practice. In doing so, we draw comparisons between the outcomes and implications of this review study with recent trends and future foci of SSI research, as reported by Bencze et al. (2020), and Zeidler et al. (2019).

Theoretical implications

The 28 studies we reviewed were all empirical studies. Each study contributed to theory in its own way, in particular, with regard to possible conceptualisations of the different morality aspects within secondary science education. In our analysis, we found that not all the studies used explicit, concrete conceptualisations of components of morality, and that they mainly focused on more than one morality component. In other words, their conceptual framework overlapped with multiple components, which were used interchangeably at times.

Within the context of morality, researchers often point to the importance of a sense of place (e.g., Kim et al., 2020; Van Den Born & Drenthen, 2011), and the situatedness of morality (Narvaez & Rest, 1995; J. R. Rest et al., 2000). In the literature, 'sense of place' is often referred to as a construct to characterise the relationship between people and spatial settings. This 'relationship' offers an opportunity for reflection (e.g., Van Den Born & Drenthen, 2011). In addition to a 'relationship to place', the literature on character education emphasises the importance of a student's social relationships, e.g., with peers, school and family. Research has shown that these have a major influence on a student's morality and character formation (e.g., Berkowitz, 1985; D.L. Zeidler & Keefer, 2003; Nucci, 1989). This has led to moral education pedagogies in which group discussions involving argumentation and discussion often play a key role. It is therefore not surprising that this pedagogical method was used in various interventions in the 28 studies. The role of 'sense of place' and the 'situatedness of morality' was often neglected in these studies, although these

concepts obviously also influence students' morality. This was evident in several studies, especially within the FCM-4 context (e.g., FCM-4.1, FCM-4.3 and FCM-4.4).

With regard to constructs for future SSI science education, which contribute to the further development of SSI pedagogy, Zeidler et al. (2019) emphasise the importance of 'socioscientific perspective taking' (SSPT), in which the emphasis is on both an 'etic to emic shift' (i.e., shift from a 'scientist-oriented approach' towards 'how local people think, how they categorize and perceive the world'), and on the moral context (e.g., Kahn & Zeidler, 2019). Both aspects correspond with the lacunae we uncovered in our analysis of the reviewed studies, namely that the 'role of the sense of place' and the 'situatedness of morality' were often neglected.

Research implications

Our review study also unearthed a number of limitations in the research literature. In terms of context, 18 of the 28 studies were conducted in North America, Scandinavia and Asia – more specifically, the United States, Canada, Sweden, Norway, Finland, China, Thailand and the Philippines – leaving a contextual knowledge gap elsewhere (e.g., African, South America and other European countries and Australia).

Moreover, many of the topics that were central to the 28 studies focused on the tense relationship between humans and nature. We could interpret topics like this in 22 studies, namely the conservation of biodiversity, sustainability, global warming, environmental toxins, GMOs, the reintroduction of native animals and the use of natural resources. However, most studies focused on ethics and values, namely ethical inquiry, moral reasoning, personal reasoning, (ethical) argumentation, perspective-taking, students' concerns, perceptions and attitudes, their moral sensitivity, personal values, risk perceptions, identities and futures thinking. On the other hand, the number of studies focusing on students' moral character and action-taking were under-represented. The studies that did focus on action-taking centred on students' intentions to take action and their self-reported views on action. We would therefore recommend that further research be carried out on the interrelationships between moral character, action-taking and enacted moral reasoning.

In terms of age representation, the participants in 17 of the 28 studies were upper secondary students, aged 15–18 years. Fewer studies (8 of the 28) had a bigger age range, with participants from lower and upper secondary education. In only three of the 28 studies were the participants lower secondary students, aged approximately 11–14 years. This leads us to conclude that the studies make a significant contribution to knowledge about the morality of 15–18-year-old students. However, morality research, with other foci and contexts, remains important for this age group. We also recommend that more research be conducted on students' morality in other age groups. For example, knowledge about morality aspects among younger (e.g., primary) students will also provide a better understanding of secondary students' morality – knowing 'where secondary (science) students are coming from'. Developmental psychology research has found that younger students are generally at different stages of moral development (cf. Kohlberg, 1976, 1986), or social perspective-taking (Selman, 1980).

Regarding SSI research, Zeidler et al. (2019) emphasise that SSI are embedded in a sociocultural view of education (cf. Bencze et al., 2020), whereby the educational

significance depends on the specific context relative to that SSI. Concurring with our recommendation to investigate morality with other foci, within other contexts and among other age groups, Zeidler et al. (2019) emphasise the importance of future research into contextual differences of morality, since they depend on SSI and culture, which enhances design and development of (local) SSI pedagogy.

Finally, the majority of studies focused on science students' viewpoints – specifically, their concerns and attitudes, personal values, (ethical) argumentation and decision-making, risk perceptions and moral sentiments. Although these insights are undoubtedly very valuable, there is a knowledge gap with regard to science teachers' knowledge and practices, and the challenges they face when implementing curriculum material aimed at encouraging students' morality.

With a view to the further development and implementation of Science-in-Context (SinC) fields, which includes SSI science education, STSE, and, in the French context, SAQ science education, Bencze et al. (2020) emphasise the (continuing) importance of teacher education, which, in addition to teaching the knowledge and skills of science content (Vision I on scientific literacy; cf. Roberts, 2007), also focusses on developing students' scientific literacy, corresponding with Vision II and III (cf. Hodson, 2008; Sjöström et al., 2017). Their position is in line with our recommendation to conduct more research into science teachers' knowledge and practices with regard to guiding and stimulating students' morality.

Implications for classroom practice

The analysis of the studies' findings provides insights for designing and enacting interventions aimed at encouraging and guiding students' morality within secondary science education. Based on this, we have distilled seven recommendations for devising meaningful SSI science education, with a focus on guiding and encouraging students' morality:

(1) Many students demonstrated compassion and concern with regard to sustainability-related topics. This shows the importance of using topics aimed at fostering the students' emotions, and with which students feel emotionally connected, which resonates with Zeidler et al. (2019), who argue that connecting emotive factors with science content contributes to learning science, as well as making decisions regarding SSI (cf. Tsai & Jack, 2019).
(2) It is critical to choose a well-considered pedagogical approach, aimed at developing the ability to take perspective. Working with decision-making and ethical frameworks, as well as participating in peer group discussions, are proven to be valuable teaching strategies that contribute to awareness of different, often conflicting, values. In addition, the justifications that students used in their arguments and decision-making were often based on values. Knowledge of the values involved helped students to understand which values were personally relevant. Reflection on these values can give them insight into their fundamental views regarding the specific topic, which is also beneficial for the quality of the argumentation and the ability to make value judgements. Analogous with the (above-mentioned) frameworks' benefit for guiding and stimulating morality, Sadler et al. (2011) explain the importance of socioscientific reasoning as a construct for (future)

SSI pedagogy. The framework pays attention to the necessary reasoning structures, thereby also taking the complex nature of SSIs into consideration, which stimulates students' in taking 'fair and equitable evidence-based decisions' (cf. Zeidler et al., 2019).

(3) A number of students used 'moral arguments' more often in their individual essays than in group activities, such as debate. This may indicate a need to support students to share their moral views with other students as they learn to take part in 'argumentative communication' (cf. Habermas, 1983, 1990), for example, about their own values and norms, as well as about the ethical quality of their culture's values and norms.

(4) Since 'morality' can be broadly conceptualised, we would recommend explicitly referring to the component, or components, of morality that are central to the studies' conceptual frameworks. This contributes to a greater understanding of morality, which can then be used in the design of future SSI science education aimed at guiding and encouraging students' morality.

(5) In order to encourage 'ethical implementation' or 'moral character', we recommend that encouragement of students' concerns, self-confidence and self-efficacy should be given a more central place in SSI science education. However, the structure and infrastructure of the school (e.g., a lack of timetable time and an overloaded curriculum) often works against this and 'moral behaviour' is often outside the school's direct influence. We therefore advocate that schools seek connections with their local communities, which gives students an opportunity for (particular) 'ethical implementation'. Similarly, we recommend that the science curriculum be critically examined with a view to creating a curriculum that pays greater attention to this morality component. These recommendations resonate with the foundational conditions of an SSPT approach to future SSI science education, in which special attention is paid to engagement, etic to emic shift and moral context (cf. Kahn & Zeidler, 2019). Furthermore, place-based SSI science education (cf. Herman, 2018) – - another important construct for future SSI science education (Zeidler et al., 2019) – - also aims to contribute to students' sociocultural awareness and their moral sensitivity by teaching and learning morality within authentic contexts.

(6) We recommend that students be encouraged to reflect on their personal values in relation to the SSI topic. Several studies provided evidence that students' justifications in their arguments and decision-making were often based on values. Reflection can give them an insight into their fundamental views, which is also beneficial for the quality of their arguments.

(7) Given the interdisciplinary nature of SSI, we recommend the inclusion of perspectives from disciplines that go beyond science in encouraging and guiding the students' morality within the SSI context. We therefore recommend that philosophy and ethics receive special attention within SSI science education, taught either by science teachers or by teachers with more training in these disciplines, such as teachers of philosophy, social science, or languages.

Concluding, in alignment with the importance of a broad conceptualisation of scientific literacy (cf. Bencze et al., 2020) – in which, in addition to teaching and learning the knowledge and skills of science (i.e., Vision I; cf. Roberts, 2007) there is also focus on knowledge

about science, and the relationship of science to economics, culture and politics – centralising students' morality development in SSI science education fits well within this broad conceptualisation. As Levinson (2018) argued, a broad approach to science education (cf. vision II and III) appears to be discouraging since in contemporary STEM education Vision I is predominantly propagated. With this review study we support the importance of a broad vision of scientific literacy. In doing so, we particularly highlighted the prominence of supporting the development of students' morality in SSI education.

Notes

1. In the literature, the term 'socioscientific issues' is sometimes written with a hyphen, i.e. 'socio-scientific issues'. Throughout this paper we adhere to Zeidler's (2014) argument that the hyphen separates the social context from the associated science. Zeidler argues that there is a danger in separating the supposedly non-normative scientific components from the normative social components, since it potentially creates a view in which the sense of responsibility is abandoned during science practice (p. 699). In this line of reasoning, one could argue that the two are inextricably linked.**Tore van der Leij**: In the 1990s I studied biology at Wageningen University & Research. My master's thesis was on the role of ethics in environmental education, and it was supervised by Arjen Wals (Wageningen University) and Bob Jickling (Yukon College/Lakehead University, Canada). During my stay at Yukon College (Whitehorse) I worked with Bob Jickling as a teaching assistant in several courses (environmental ethics, environmental philosophy, environmental education).After completion of my biology master's program, I obtained my teaching degree at Utrecht University. From 1998 onwards I have been working as a biology teacher in several Dutch high schools. In 2016 I received a scholarship for conducting PhD research in the field of science education, in addition to our job at school. The program is funded by the Dutch Ministry of Education, Culture and Science.**Lucy Avraamidou**: I am a Rosalind Franklin Fellow and an Associate Professor of Science Education at the Institute for Science Education and Communication. I was born and raised in Cyprus where I worked as an Assistant/Associate Professor of Science Education at the University of Nicosia (2006–2016) and at the Open University Cyprus (2015-2016).I received my M.Sc (2001) and PhD (2003) in Curriculum and Instruction with a specialisation in Science Education from the Pennsylvania State University in the USA. Upon its completion I worked as a Research Associate at the NSF-funded Center of Informal Learning and Schools (CILS) at King's College London.My research is associated with theoretical and empirical explorations of what it means to widen and diversify STEM participation in school and out-of-school settings through the lens of intersectionality. At the heart of the account of my work is an exploration of minoritized individuals' identity trajectories and negotiations with the use of narrative and life-history methods.I have worked as a principal investigator and researcher on projects funded by the National Science Foundation in the USA, the European Union, the Cyprus Research Promotion Foundation, and the United Nations Development Program. I have authored more than 100 publications and I edited 4 book volumes.**Arjen Wals**: Arjen Wals is a Professor of Transformative Learning for Socio-Ecological Sustainability at Wageningen University. He also holds the UNESCO Chair of Social Learning and Sustainable Development. Wals is alo a Visiting Professor at Norwegian Life Science University in Ås where he supports the development of Whole Schools Approaches & Sustainability.His recent work focusses on transformative social learning in vital coalitions of multiple stakeholders at the interface of science and society. His teaching and research focus on designing learning processes and learning spaces that enable people to contribute meaningfully sustainability. A central question in his work is: how to create conditions that support (new) forms of learning which take full advantage of the diversity, creativity and resourcefulness that is all around us, but so far remain largely untapped in our search for a world that is more sustainable than the one currently in prospect?**Martin Goedhart**: After

graduation in biochemistry at Utrecht University in 1980, I started my career as a chemistry teacher at a vocational school for laboratory technicians. Many students had problems in understanding the abstract concepts in these subjects. These problems were hard to overcome and I became more interested in theory about science teaching and learning. Therefore, I became very interested to start a PhD project in chemical education at Utrecht University in 1984. I investigated the way undergraduate students design measurements in physical and analytical chemistry in a research-oriented laboratory course.After having gained my PhD (1990) and after a post-doc period in Utrecht, I moved to a vocational school in Leiden, and two years later I got a position as assistant professor at the University of Amsterdam. I lectured chemistry education at the Teacher Training Institute and supervised prospective chemistry teachers during their internship at high school. My main research interests during that period were the development of pre-service teachers, and conceptual development. After some years I moved to the science faculty and coordinated research activities in mathematics and science education at the AMSTEL institute.Since 2004 I have a position as full professor in mathematics and science education. I am head of the department and director of the master programme in Mathematics and Science Education and Communication. My main research areas are argumentation, scientific literacy, and mathematical reasoning.

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