THE PROMOTION OF SOCIOSCIENTIFIC DECISION-MAKING

ADDRESSING FOUR CHALLENGES IN SCIENCE EDUCATION PRACTICE AND RESEARCH

DOCTORAL THESIS

SUBMITTED WITH RESPECT TO THE REQUIREMENTS FOR THE DOCTORAL DEGREE

Dr. rer. nat.

TO THE FACULTY OF MATHEMATICS AND NATURAL SCIENCES OF THE *CHRISTIAN-ALBRECHTS-UNIVERSITÄT ZU KIEL*

SUBMITTED BY

CAROLA Y. GARRECHT

KIEL, JULY 2020

First reviewer:	Prof. Dr. Ute Harms
Second reviewer:	Prof. Michael J. Reiss
Date of defence:	September 28th, 2020

SUMMARY

A central objective of science education is to prepare students for the negotiation of science-related social issues (i.e., socioscientific issues) and to support them in reaching informed decisions. The ability to include both scientific and normative considerations into the negotiation has been summarized under the term *socioscientific decision-making*. Although socioscientific decision-making has been widely acknowledged as an essential component of students' scientific literacy, difficulties remain concerning its promotion and assessment. In a first step, this dissertation outlines four challenges connected to the development of students' socioscientific decision-making from a teaching-learning perspective (Challenge 1: The structure of the learning environment; Challenge 2: The complexity of socioscientific issues) and from a measurement perspective (Challenge 3: Conceptualization of socioscientific decision-making; Challenge 4: Assessment of socioscientific decision-making).

To address the aforementioned challenges, three studies have been carried out as part of this dissertation. Each study aimed to extend the current knowledge about the development of students' socioscientific decision-making in formal and non-formal learning opportunities. Study 1 comprises a systematic literature review, which considers empirical studies that explore the promotion of (1) students' socioscientific decision-making in (2) sustainability-related and (3) extracurricular learning opportunities. Two different notions of socioscientific decision-making have been revealed as part of the results: Decision-making as a rational and mostly individual, and as a more cooperative, socially embedded process. Furthermore, no studies have been found with an equal distribution of attention among all three components. This shortcoming has been empirically investigated in Study 2, which assesses a sustainability-related extracurricular learning opportunity (an environmental science competition) in its effectiveness to promote participants' socioscientific decision-making. The analysis of data supports the conceptualization of socioscientific decision-making as a multi-phased process; a conceptualization which has already been recognized among the science education community. On the other hand, the results from Study 2 confirm the presence of the two previously identified notions. The findings further suggest that participating in this science competition predominantly fosters the preparational phase of socioscientific decision-making. In contrast to Study 1 and Study 2, Study 3 focuses on formal learning opportunities (i.e., the regular classroom) and examines students' argumentation as part of their decision-making process. The results of Study 3 provide evidence that an increase in issue familiarity does not enhance the *diversity* of argument types presented by students; however, the *depth* of already predominant types is manifested.

Using both quantitative and qualitative methods, this dissertation provides novel insights into the promotion and assessment of students' socioscientific decision-making by addressing the four previously identified challenges. The present work concludes with two final recommendations for contemporary science education. First, more attention should be paid to extracurricular learning opportunities, as they can empower students to investigate socioscientific issues that are meaningful to *their* lives. The second recommendation stresses the value of interdisciplinary working for the negotiation of complex socioscientific issues and thus the development of students' socioscientific decision-making.

ZUSAMMENFASSUNG

Eine zentrale Aufgabe naturwissenschaftlichen Unterrichts ist es, Schülerinnen und Schüler auf die Bearbeitung gesellschaftlich relevanter Fragen vorzubereiten, die neben sozialen auch naturwissenschaftliche Komponenten aufweisen (*socioscientific issues*), und sie in ihrer Meinungsbildung zu unterstützen. Die Fähigkeit, sowohl naturwissenschaftliche als auch normative Überlegungen in die Bearbeitung von *socioscientific issues* einzubeziehen, wird unter dem Begriff *Bewertungskompetenz* zusammengefasst. Obwohl sie als ein essenzieller Bestandteil naturwissenschaftlicher Grundbildung angesehen wird, treten Schwierigkeiten bei der Förderung und Erfassung von Bewertungskompetenz auf. In einem ersten Schritt skizziert diese Arbeit vier Herausforderungen, welche die Entwicklung von Bewertungskompetenz sowohl aus einer Lehr-Lernperspektive (Herausforderung 1: strukturelle Gegebenheiten von Lerngelegenheiten; Herausforderung 2: die Komplexität von *socioscientific issues*) als auch in Bezug auf ihre Messbarkeit (Herausforderung 3: Konzeptualisierung von Bewertungskompetenz; Herausforderung 4: Erfassung von Bewertungskompetenz) adressieren.

Um diese vier Herausforderungen zu betrachten, wurden im Rahmen dieses Dissertationsprojekts drei Studien durchgeführt. Jede Studie verfolgte dabei das Ziel, den aktuellen Wissensstand zur Förderung und Erfassung von Bewertungskompetenz in formalen und non-formalen Bildungsangeboten zu erweitern. Studie 1 umfasst eine systematische Literaturanalyse. Berücksichtigt wurden empirische Studien, welche die (1) Förderung von Bewertungskompetenz in (2) nachhaltigkeitsbezogenen und (3) extracurricularen Lerngelegenheiten untersuchen. In den Ergebnissen der Analyse wurden zwei unterschiedliche Betrachtungsweisen identifiziert: Bewerten als ein rationaler und überwiegend individueller oder als ein kooperativer und sozial eingebundener Prozess. Darüber hinaus wurde keine Studie gefunden, die alle drei Komponenten zu gleichen Teilen in ihre Betrachtung einbezieht. Dies wurde in Studie 2 empirisch umgesetzt, in der die Effekte einer nachhaltigkeitsbezogenen und extracurricularen Lerngelegenheit (eines naturwissenschaftlichen Schülerwettbewerbs) auf die Entwicklung von Bewertungskompetenz bei Teilnehmenden untersucht wurden. Die Auswertung der Daten von Studie 2 unterstützt zum einen die bereits in Fachkreisen anerkannte Konzeptualisierung von Bewertungskompetenz als mehrphasigen Prozess. Zum anderen unterstützen die Ergebnisse die zwei zuvor identifizierten Betrachtungsweisen. Die Befunde der Studie 2 zeigen außerdem, dass der Wettbewerb Teilnehmende überwiegend in der Vorbereitungsphase des Bewertungsprozesses unterstützt. Im Gegensatz zu Studie 1 und Studie 2 widmet sich Studie 3 den formalen Lerngelegenheiten (hier: dem regulären Klassenraum) und untersucht die Argumentation von Schülerinnen und Schülern als Teil ihres Bewertungsprozesses. Die Ergebnisse aus Studie 3 zeigen, dass eine gesteigerte Vertrautheit mit dem zugrundeliegenden *socioscientific issue* nicht die Vielfalt verschiedener Typen von Argumenten steigert, sondern die Tiefe der bereits vorherrschenden Typen verstärkt.

Unter Einsatz sowohl quantitativer als auch qualitativer Methoden ermöglicht diese Dissertation neue Einblicke in die Förderung und Erfassung von Bewertungskompetenz. Abschließend werden zwei Empfehlungen für einen zeitgemäßen naturwissenschaftlichen Unterricht gegeben. Erstens sollten extracurriculare Lerngelegenheiten stärker in den Blick genommen werden, da sie Schülerinnen und Schülern die Möglichkeit bieten, relevante Probleme ihrer Lebenswelt zu untersuchen. Zweitens sollte interdisziplinäres Arbeiten bewusster in die Lehr-Lernkultur integriert werden, da es die Komplexität von *socioscientific issues* berücksichtigt und die Entwicklung von Bewertungskompetenz unterstützen kann.

TABLE OF CONTENTS

LIST OF FIGURES

THEORETICAL BACKGROUND (Chapter 2)

STUDY 1 (Chapter 4)

STUDY 2 (Chapter 5)

STUDY 3 (Chapter 6)

DISCUSSION (Chapter 8)

LIST OF TABLES

1. INTRODUCTION

The outbreak of COVID-19 caused one of the greatest health emergencies of the 21st century. In order to prevent the further spread of the virus, each individual is required to make responsible decisions on how to behave (see also Paakkari & Okan, 2020).

The term COVID-19 describes an infectious disease that is caused by a coronavirus called SARS-CoV-2. To initiate responsible behavior, individuals are required to understand how different actions can impact viral spread (e.g., social distancing or hand washing). This presupposes a basic scientific understanding. On the other hand, dealing with this pandemic also involves normative considerations. This might entail acknowledging the social consequences of governmental measures (e.g., lockdown) and touches upon the mental distress experienced by individuals during this crisis (e.g., Jiao et al., 2020; Schimmenti, Billieux, & Starcevic, 2020).

As a result, the outbreak of COVID-19 represents a factually and ethically complex issue that, while being rooted in science, is of high societal importance (i.e., a socioscientific issue, Sadler, 2004). While German school students slowly return to their classrooms, the question remains how science education can promote the cultivation of scientifically literate individuals capable of facing such challenges today and in the future.

Under the aegis of *The Future of Education and Skills: Education 2030* (OECD, 2019), educational scholars from around the globe discuss how to equip students with the knowledge, skills, values, and attitudes that will be needed in the future. To actively involve students in shaping future societies, three ‘transformative competences’ have been identified: (1) creating new values (i.e., challenging the status quo), (2) reconciling tensions and dilemmas (i.e., acknowledging the inherent complexity of problems), and (3) taking responsibility (i.e., reflecting upon personal and societal ambitions). Translated into the context of science education, these ‘transformative competences’ are broadly aligned with students’ socioscientific decision-making, which describes students’ informed negotiation of science-related social issues (Lee & Grace, 2010).

Although socioscientific decision-making has been greatly emphasized as an essential component of students’ scientific literacy (e.g., Bögeholz, Böhm, Eggert, & Barkmann, 2014; Lee & Grace, 2010; Reitschert & Hößle, 2007; Zeidler, Herman, & Sadler, 2019), there are still many challenges connected to its promotion and its assessment (see also Eggert, 2016). These challenges substantially motivated this work, which aims to provide new insights into students’ development of socioscientific decision-making from both a teaching-learning and a measurement perspective.

The following chapters can be divided into three major parts. The first and introductory part presents the theoretical background of this work and concludes with four challenges concerning students’ development of socioscientific decision-making (Chapter 2). The following chapter (Chapter 3) introduces the aim of this dissertation and briefly outlines the conducted studies. The second part of this dissertation includes the research articles and the manuscript of three studies which have been conducted during the course of this dissertation (Chapter 4-6). The final part entails the concluding chapters which discuss the studies’ results and scheme implications for science education research and practice (Chapter 7-9).

2. THEORETICAL BACKGROUND

2.1. Scientific literacy

An essential objective of science education is to provide students with an understanding of science that allows them to participate in science-related conversations that occur in their personal lives and the broader society (DeBoer, 2000). This knowledgeability, encompassing all science learning experiences, is commonly subsumed under the term *scientific literacy* (Roberts & Bybee, 2014). Starting in the late 1950s, the aim to promote students' scientific literacy has appeared repeatedly in educational policy documents, assessment programs, and research studies (Holbrook & Rannikmae, 2009; Roberts & Bybee, 2014; Sadler & Zeidler, 2009). However, the tremendous amount of divergent definitions presented within these documents indicates that no clear-cut consensus exists among the science education community regarding what genuinely constitutes a scientifically literate individual (Laugksch, 2000; Roberts, 2007).

A systemized approach that illustrates the different perceptions of scientific literacy is offered by Roberts (2007), who distinguishes between two opposite 'visions': Vision I and Vision II.

Science education that aligns with Vision I introduces the learner to knowing science in terms of mastering the fundamental ideas, content, and skills necessary for scientific inquiry. The primary aim of science education is, therefore, to acquaint students with the foundations of science and scientific thinking, conveying a knowledgeability that enables students to understand scientific issues "as a scientist would" (Roberts, 2007, p. 767). This more 'inward' perspective on science stresses the decisive role of the scientific community to define *what* content and practices are deemed important to know for a scientifically literate individual (Romine, Sadler, & Kinslow, 2017). Aikenhead (2006) categorized this type of knowledgeability as "wish-they-knew science" (p. 31), illustrating the interest of the science community to advocate science education that is relevant to those who will enter the field of science professionally in the future (Osborne, 2007).

To argue that science education should predominantly revolve around the preparation of future scientists has increasingly evoked critical voices. Reiss (2017) as well as Osborne and Dillon (2008), for example, emphasize that only a small number of students will enter the field of science on a professional basis. This comment reveals the substantial concern that science education, in this case, would only benefit the few and not the vast majority. Besides, a mere focus on the scientific content and practices necessary for scientific inquiry potentially dissatisfies students, as argued by several scholars, because students might perceive their science learning as too detached from their real lives (e.g., Holbrook, 2005; Lyons, 2006; Osborne & Collins, 2001).

Vision II responds to these critical points by focusing on the value of science in contexts connected to students' personal lives and for the broader society. Advocates of Vision II take a more externally oriented perspective concerning the purpose of science education (Roberts, 2007). Instead of focusing on the products and processes *within* science, Vision II drives meaning from science-related social situations. The primary aim of science education, resulting from this social embeddedness, concerns students' abilities to apply their scientific understanding *outside* the science classroom (Roberts & Bybee, 2014; Sadler & Zeidler, 2009). This functional aspect of Vision II is described as students' "need-to-know science" (Aikenhead, 2006, p. 33). It is this second vision that acknowledges students as responsible and participatory individuals in a scientifically complex world (DeBoer, 2000; Duschl, Schweingruber, & Shouse, 2007; Holbrook & Rannikmae, 2007; Holbrook & Rannikmae, 2009).

Although Roberts (2007) separates each vision as the endpoints of a continuum, he also argues for their co-existing by clarifying that both visions have merit for educational considerations, from developing curricula to designing research. As a result, many science education curricula around the globe consider aspects of both Vision I *and* Vision II (either explicitly or implicitly; Hofstein, Eilks, & Bybee, 2011; Holbrook & Rannikmae, 2009). However, despite their theoretical co-existence, several scholars have claimed a predominance of Vision I with respect to the practical implementation of these curricula (e.g., Aikenhead, 2006; DeBoer, 2000; Zeidler, Applebaum, & Sadler, 2011). A possible explanation might be that science education that aligns with Vision I enjoys a long tradition in the Western world, which potentially leads to a lethargy of change (see also Osborne, 2007). A more substantial inclusion of Vision II, on the contrary, might require more progressive movements among the science education community.

Take-away definition for scientific literacy: *One of the essential aims of contemporary science education is to educate students as scientifically literate individuals. This knowledgeability considers students' understanding of scientific ideas and practices (Vision I) but also stresses their abilities to apply this understanding beyond the school setting (Vision II). The definition of scientific literacy used to reflect upon the work of this dissertation aligns with Vision II. It frames students as responsible citizens "solving personally challenging yet meaningful scientific problems as well as making, responsible socio-scientific decisions" (Holbrook & Rannikmae, 2009, p. 286).*

2.1.1. Curricular movements targeting the integration of Vision II

In his examination of the historical and contemporary meanings of scientific literacy, DeBoer (2000) outlines the cultivation of a "public that finds science interesting and important, who can apply science to their own lives, and who can take part in the conversations regarding science that take place in society" (p. 598; i.e., Vision II scientific literacy) as the ultimate interest of science education. To meet this demand, several educational initiatives established frameworks that explicitly focus on social contexts for science learning (e.g., Science-Technology-Society [STS; Yager, 1993]; Science, technology, society and environment [STSE; Pedretti, 2003]; Science, Technology, Engineering, Arts, and Mathematics [STEAM; Colucci-Gray, Burnard, Gray, & Cooke, 2019]; Socioscientific issues [SSI; Sadler, 2004]; see also Bencze et al., 2020).

The Science-Technology-Society (STS) movement is one of the above mentioned curriculum approaches that significantly impacted the alignment of contemporary science education (Mansour, 2009). Its main intention is to make science learning more meaningful to students. It therefore utilizes societal contexts to exemplify how science and technology can affect the larger society and students' personal lives (Yager, 1993). Over the last thirty years, the STS movement has received a great amount of feedback from within the science education community. Hodson (2003), for example, summarizes that recognizing the interrelationship between science and society, instead of understanding them as two separate entities, constitutes an important step towards a more holistic understanding of science learning. On the other hand, as critically noted in Zeidler, Sadler, Simmons, and Howes (2005), the STS movement also tends to overemphasize students' scientific and technology-related knowledge in the negotiation of societal issues. The authors further argue that simply placing students' scientific knowledge within social contexts neglects their personal beliefs and the various types of knowledge that they bring into the discussion. The social contexts which were originally assumed to increase personal meaning thus appear detached from students' individual worldview. As a result, the STS approach struggles to engage students in the exploration of the embedded moral implications (Zeidler et al., 2005; Zeidler, 2014; 2016).

The socioscientific issue (SSI) movement has been established to address these concerns by empowering students to consider the ethical dimension of science and scientific inquiry (Zeidler, 2014). Just like the STS movement, the SSI movement pursues similar core intentions (i.e., students' cognitive development) while additionally stressing students' moral growth (Sadler & Zeidler, 2004; Zeidler et al., 2005). Within this more recent movement, science-related social issues serve as a platform to give audience to students' personal perspectives, including their own knowledge and belief systems (Kolstø, 2001; Zeidler et al., 2005). In a simplified form, Figure 2.1 compares the role of science-related social issues for students' science learning in both movements.

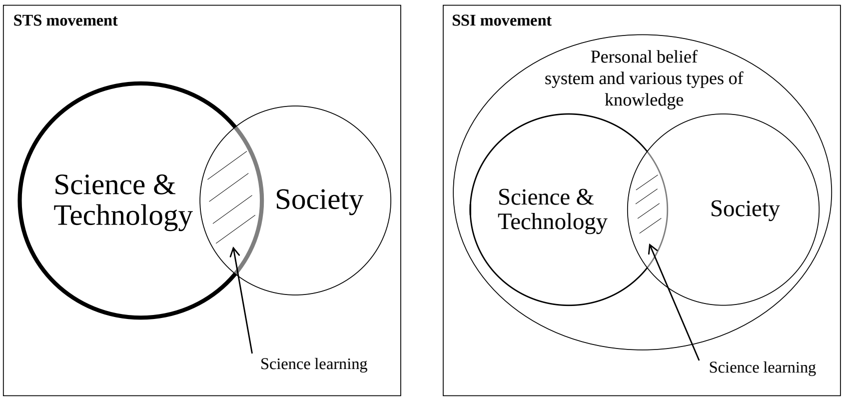

Figure 2.1: Science learning according to the STS (left) and the SSI (right) movement.

2.1.2. SSI as particular type of problem

Besides referring to an educational movement, the term SSI[1] also describes a specific type of problem that represents a central element of the movement (Pope, 2017). In the latter sense, SSI characterize authentic problems that are controversially debated within society (*socio*-), which also display process-related and/or conceptual links to science (*scientific*; Fleming, 1986; Sadler, 2011). Examples of current SSI include global warming, genetic engineering, or the loss of biodiversity. Located at the intersection of science and society, SSI require more than just scientific knowledge for their negotiation (Sadler, 2004). In addition to this descriptive dimension, students must also develop a normative awareness. This includes acknowledging and balancing competing interests and differing value systems that are represented in pluralist societies (Kolstø, 2006; Sadler, 2004). Due to these multiple interests that are interwoven into the problem, SSI do not have a straightforward or clear-cut solution and can be considered as inherently complex (Kolstø, 2001).

To help researchers and practitioners reflecting upon the potentials of an SSI for the science classroom, Stolz, Witteck, Marks, and Eilks (2013) identified five criteria that should be met: The SSI under consideration should be (1) authentic, (2) relevant (3) controversial (i.e., allows multiple perspectives), (4) open for discussion, and (5) science- or technology-related. Zeidler and Sadler (2008) further claim that suitable SSI also require the (6) elaboration of an ethical stance which is therefore added as a sixth criterion.

2.1.3. The SSI framework

The SSI framework, which substantiates and guides the respective movement, acknowledges students' personal perspectives, belief system, and various types of knowledge that they bring into the science classroom by targeting students' holistic development (i.e., cognitive *and* moral growth; Ratcliffe & Grace, 2003; Zeidler et al., 2005; Zeidler, 2014). The framework determines four areas of pedagogical importance (Zeidler et al., 2005):

1. *Nature of Science issues*: Considers, for example, how students choose and evaluate scientific evidence
2. *Classroom discourse*: Focuses on the role of discourse for the construction of shared knowledge and understanding
3. *Cultural issues*: Recognizes and addresses the pluralistic aspects of the classroom and stresses the multi-perspectival complexity of SSI (as an issue)
4. *Case-based issues*: Considers the use of SSI (as an issue) to stimulate students' ethical considerations.

Teaching in accordance with the SSI framework can offer entry points for science learning which fosters what Zeidler et al. (2005) call "functional" (p. 361) scientific literacy. The

[1] SSI is used as an abbreviation for both the singular and the plural (see also Zeidler et al., 2019).

word functional refers to the application of science and science understanding in order to fulfil a function in society. Therefore, functional scientific literacy can be viewed as closely aligned with Robert's Vision II (see also Laugksch, 2000).

2.1.4. Suitable learning environments for the implementation of SSI

Within the last two decades, an impressive body of research portrayed the educational benefits connected to the implementation of SSI. Using SSI as contexts for science learning has been shown, for example, to develop students' science content knowledge (e.g., Klosterman & Sadler, 2010), to expand their epistemic understanding (e.g., Eastwood et al., 2012; Sadler, 2009), to support the cultivation of scientific identities (e.g., Simonneaux & Simonneaux, 2009), to advance their scientific thinking and working (e.g. reasoning and argumentation; Dawson & Venville, 2010; Walker & Zeidler, 2007), and to engage students in reflective judgments and informed decision-making (e.g., Eggert & Bögeholz, 2010; Zeidler, Sadler, Applebaum, & Callahan, 2009).

To support and achieve such developments a suitable learning environment must be ensured. Whereas science education that aligns with Vision I relies on a long tradition in the Western world, the inclusion of science learning initiatives targeting Vision II (i.e., SSI movement) requires a "deep restructuring" (Zeidler et al., 2011, p. 279) of traditional science education practices (Osborne, 2007). In the following, two conflicting ideas of classroom practice (i.e., the traditional and the progressive classroom) will be briefly outlined. Both practices have to be seen as extreme endpoints on a teaching continuum whereas the characteristics of each will be slightly exaggerated for illustrative purposes.

The traditional classroom: Traditional classroom instruction mirrors an understanding of science that is closely aligned with Vision I scientific literacy (Zeidler, 2014). In its very nature, instructions are subject to a positivist worldview, presenting knowledge as something objective that can be received from textbooks or experimental designs (Zacharia & Calabrese Barton, 2004). The teacher holds an authoritative position in this type of classroom, which can be explained by his or her duty to transmit the previously determined knowledge (Zeidler et al., 2011; Zeidler, 2014). Students, who are perceived as consumers of ready-made and non-negotiable science knowledge, are at the more passive end of the spectrum, reacting to the prompts and demands of the teacher (Lemke, 1990; Scott, Mortimer, & Aguiar, 2006).

The progressive classroom: The progressive classroom culture, which can be associated with Vision II scientific literacy, is located on the other side of the teaching continuum. Instructions are built upon a constructive worldview, presenting knowledge formation as a "result of students' deliberative conversations about authentic problems that allows them to become active participants in democratic decision-making" (Zeidler et al., 2019, p. 1). The classroom culture is, conclusively, less authoritative and more dialogic, featuring highly engaging practices such as critical thinking and argumentation (Berland et al., 2016; Lee, Lee, & Zeidler, 2019; Scott et al., 2006; Zeidler, 2014).

As clarified in Zeidler et al. (2011), the SSI movement can be located at the progressive end of the outlined teaching continuum. A suitable learning environment for SSI instruction, concluding from the previous section, tries to "mirror the discourse practices used in real life" (Zeidler et al., 2019, p. 4). This offers students the opportunity to explore science-related social issues from their personal perspective and to engage in responsible and informed decision-making.

2.1.5. Summary of Chapter 2.1

The considerations undertaken within this chapter to set the stage for the work of this dissertation are summarized in Figure 2.2.

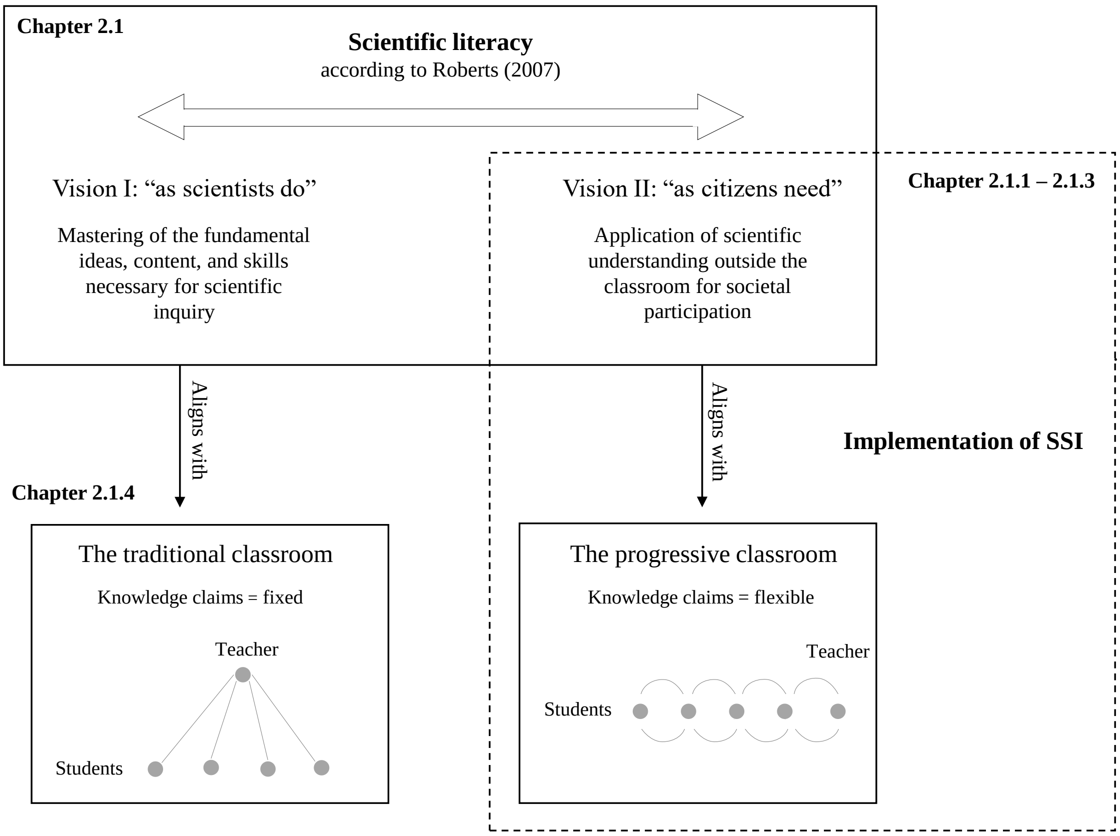

Figure 2.2: The main considerations from Chapter 2.1.

2.2. Socioscientific decision-making in science education

Based on the vast body of research conducted in the field of cognitive psychology, the existence of dual-process models for decision-making has been widely accepted (for a review, see Gerrard, Gibbons, Houlihan, Stock, & Pomery, 2008). These models assume that decision-making operates in two different systems of thinking: An intuitive ('system 1') and an analytical one ('system 2'). System 1 initiates informal decision-making, which is characterized by a parallel and rather rapid processing of information. This intuitive procedure is considered as relatively effortless by the decision-maker (Gigerenzer & Brighton, 2009; Glöckner & Betsch, 2008; Kahneman & Frederick, 2002). On the contrary, decisions that are made within system 2 engage people in rational thinking (i.e., formal decision-making). This intentional decision-making is cognitively challenging and contains the analytical, sequential, and thus slower examination of the given information (Betsch, 2008). This dissertation refers to the second system which focuses on deliberate decision-making in *complex* problems (Wilson & Keil, 2001).

Living in modern, scientifically- and technologically-advanced societies increasingly means being confronted with complex SSI (Zeidler & Lewis, 2003). For societal participation, students require the necessary abilities to apply their (scientific) understanding to reach well-informed decisions (Böttcher & Meisert, 2013; Hedtke, 2016). To support students' socioscientific decision-making has consequently become a central interest of contemporary science education (KMK, 2005a, KMK, 2005b, KMK, 2005c; NGSS, 2013; NRC, 2012) and the respective field of research (e.g., Eggert & Bögeholz, 2010; Grace, 2009; Gresch, Hasselhorn, & Bögeholz, 2013; Lee, 2007).

However, negotiating SSI to derive an informed view is considered a cognitively demanding endeavor. First, the presence of two different dimensions – a descriptive and a normative one – needs to be recognized: Despite their prominent links to science, coping with these issues cannot exclusively rely on scientific considerations (Eggert, Ostermeyer, Hasselhorn, & Bögeholz, 2013; Jho, Yoon, & Kim, 2014). Instead, navigating these problems has to touch equally upon a normative dimension, meaning that ethical considerations are a vital element of their negotiation (Lee, 2007; Zeidler, 2014). Secondly, SSI are open-ended and controversially discussed problems (Kolstø, 2006). A central aspect of dealing with these issues is, therefore, to contemplate multiple perspectives while acknowledging that each solution approach holds advantages and disadvantages, depending on the taken perspective (Jiménez-Aleixandre, 2002; Liu, Lin, & Tsai, 2011; Sadler, 2009; Sadler, Barab, & Scott, 2007; Sadler & Zeidler, 2005; Wu & Tsai, 2007). Figure 2.3 illustrates this complexity.

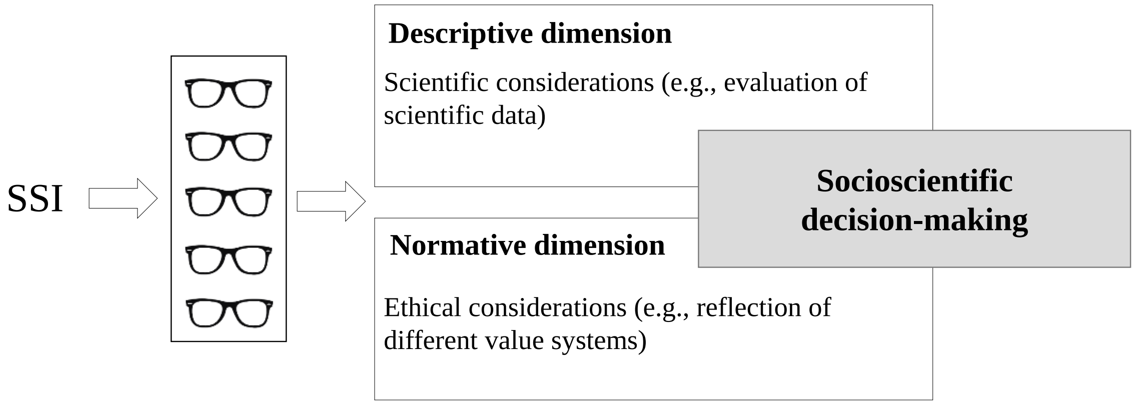

Figure 2.3: Socioscientific decision-making as a complex undertaking that includes the consideration of multiple perspectives (different viewpoints are represented by the glasses) and dimensions.

2.2.1. An overarching framework for socioscientific decision-making

With the aim of establishing a theoretical framework that conceptualizes socioscientific decision-making in science education, Fang, Hsu, and Lin (2019) investigated a variety of models that have been published in the past decades (e.g., Acar, Turkmen, & Roychoudhury, 2010; Lee & Grace, 2012; Ratcliffe, 1997). Resulting from their review of literature, Fang and colleagues then developed an overarching framework that comprises three interconnected phases of socioscientific decision-making:

Phase 1: The first phase deals with the preparation of the decision-making process and focuses on students' abilities to identify and define a proper decision-making space. In a first step, this contains the search and selection of information necessary for gaining basic familiarity with the issue. In a second step, this information is evaluated and reasoned to postulate possible solutions. Because these activities describe students' engagement with processes that happen *before* making a (final) decision, this first phase is also called the pre-selectional phase (Betsch & Haberstroh, 2005a).
Phase 2: The second phase comprises students' selection of appropriate decision-making strategies and is, therefore, called the selectional phase (Betsch & Haberstroh, 2005a). Decision-making strategies are used to evaluate, compare, and decide upon the previously proposed solutions (e.g., compensatory strategy: Systematic evaluation of all the given options by making trade-offs). Phase 2 is situated immediately prior to making a (final) decision.
Phase 3: The last phase follows directly after the act of making a decision. It engages students in the deliberate reflection upon their decision-making process (phases 1 to 3) and also includes the implementation of the decision.

The theoretical framework by Fang et al. (2019) conceptualizes socioscientific decision-making as more than solely the act of making a decision. Rather than focusing on the final product (i.e., the decision which is situated between phase 2 and phase 3), socioscientific decision-making is considered as a multi-phased process which also includes the preparation of a decision (negotiation of SSI; phase 1), the selection of decision-making strategies (evaluation of options; phase 2), as well as a retrospective reflection (phase 3).

> ***Take-away definition for socioscientific decision-making:*** *Socioscientific decision-making concerns students' multi-perspectival negotiation of SSI that requires scientific as well as ethical considerations (Lee & Grace, 2010; 2012). It describes a multi-phased and cognitively demanding process which can "pose high processing demands on students" (Sakschewski, Eggert, Schneider, & Bögeholz, 2014, p. 2293).*

2.2.2. Socioscientific decision-making in German science education

Twenty years ago, the mediocre performance of German students in the Programme for International Student Assessment (PISA) reinforced the debate about the aims and outcomes of German science education (Bögeholz et al., 2014; Bögeholz, Eggert, Ziese, & Hasselhorn, 2017; Kiper & Kattmann, 2003). Driven by the publicly expressed concerns regarding the efficacy of the Germany education system, the idea of 'efficient' science education grew beyond the mere transmission of knowledge (i.e., Vision I; input-orientation) towards a science learning that supports the acquisition and utilization of competencies (i.e., Vision II; output-orientation; KMK, 2019; Moschner, 2003; Weinert, 2001). A short time later, the national educational standards for science education (including biology, chemistry, and physics education) were introduced encompassing four distinctive competence areas: 'Fachwissen' [factual knowledge], 'Erkenntnisgewinnung' [scientific inquiry], 'Kommunikation' [communication], and 'Bewerten' [socioscientific decision-making][2] (KMK, 2005a, KMK, 2005b, KMK, 2005c). With the release of these new standards for science education and explicitly its fourth competence area 'Bewerten', German science education acknowledges students' ethical considerations as part of their scientific literacy (see also Hostenbach et al., 2011).

Despite its vivid links to all sciences (biology, chemistry, and physics), socioscientific decision-making plays a particularly important role in biological contexts. This assumption is fuelled by the rapid developments in biotechnological and medical procedures, such as advancements in gene engineering or cloning technologies, and their presence in the media (Bowmaker, 2006). The large number of societal questions rooting in biology-related contexts highlights the extraordinary responsibility for *biology education* to prepare students for making informed decisions (Hößle & Alfs, 2014; Hostenbach et al., 2011).

Shortly summarized, socioscientific decision-making in German biology education requires students to:

- Differentiate between normative and descriptive statements
- Evaluate different courses of action for their own health and society

[2] Similar translations of the four competence areas for science education have been used in Bernholt, Eggert, and Kulgemeyer (2012).

- Show a normative awareness when describing and assessing scientific inquiry
- Negotiate topics related to the human-animal-relationship
- Negotiate sustainability-related issues (KMK, 2005a).

2.2.3. Socioscientific decision-making in science education research

Two of the most prominent competence models for the structuring and the development of socioscientific decision-making root in the field of biology education research (Bögeholz, 2016; Hostenbach et al., 2011): The Oldenburger competence model for moral judgment (Reitschert, Langlet, Hößle, Mittelsten Scheid, & Schlüter, 2007) and the Göttinger competence model for socioscientific decision-making (Eggert & Bögeholz, 2006). Both models can be outlined and distinguished by three characteristics: Theme, theoretical grounding, and predominant research approach.

The Oldenburger competence model for moral judgment concerns students' abilities to negotiate SSI that are connected to biotechnological and medical advancements (Reitschert et al., 2007). According to Reitschert and Hößle (2007), the theoretical development of this model is grounded in philosophical concepts and moral psychology (e.g., Kohlberg, 1976). It encompasses seven competence dimensions including students' 'recognition of own attitude', 'awareness of ethical relevance', 'evaluation', 'reflection of consequences', 'change of perspectives', 'argumentation', and 'ethical knowledge' (see also Hößle & Alfs, 2014). Most of the research concerning this model has been from a qualitative nature (Bögeholz, 2016).

The Göttinger competence model for socioscientific decision-making, on the other hand, focuses on students' decision-making in sustainability-related issues (Eggert & Bögeholz, 2006). The development of this model is based upon a descriptive model from decision theory by Betsch and Haberstroh (2005b) and the respective research predominantly focuses on quantitative research approaches (Bögeholz, 2016). Since this illustrates, on a national level, an exemplary model for decision-making in science education that mirrors the multi-phased understanding as outlined in Fang et al. (2019), this dissertation predominantly focuses on the Göttinger competence model.

2.2.3.1. Göttinger competence model for socioscientific decision-making

The Göttinger competence model for socioscientific decision-making by Eggert and Bögeholz (2006) concerns students' decision-making in sustainability-related questions. The Göttinger competence model comprises four empirically validated competence dimensions:

The first dimension, called *understanding and reflecting values and norms*, considers students' abilities to identify and discuss the normative principles connected to the concept of sustainable development (Bögeholz et al., 2014). This encompasses, for example, striving for global justice or intergenerational responsibility (see also Brundtland Commission, 1987). On a more personal level, this first dimension is also interested in students' abilities to reflect their own ideas and values involved in this debate (Eggert & Bögeholz, 2006).

The second dimension, termed *developing and reflecting solutions*, focuses on students' abilities to recognize and address the complexity of sustainable development. This includes, for example, identifying the controversial interests that are displayed by various stakeholders (Chapter 2.3.1 presents a more detailed analysis of the concept's complexity). A central aspect of this second dimension is, consequently, to assess how students obtain and process different information to suggest possible solutions (Bögeholz et al., 2014; Eggert & Bögeholz, 2006).

Since these first two competence dimensions are concerned with the *preparation* of a decision situation, they are associated with the pre-selectional phase of decision-making (Betsch & Haberstroh, 2005a; Bögeholz, 2007).

The third competence dimension, called *evaluating and reflecting solutions qualitatively*, encompasses students' abilities to compare the previously developed solutions (Bögeholz et al., 2014). Given the controversial nature of sustainable development, students are commonly confronted with various possibilities (Gresch et al., 2013). To make an informed decision thus requires students to utilize suitable decision-making strategies. An elaborate strategy for decision-making in sustainability-related situations is the systematic evaluation of all given information regarding its advantageous and disadvantageous features (i.e., compensatory decision-making strategy; Eggert & Bögeholz, 2010; Jungermann, Pfister, & Fischer, 2005).

The last dimension, which was added to the model a couple of years later, focuses on students' abilities to reflect upon the solutions' effectiveness from an economic perspective (*evaluating and reflecting solutions quantitatively-economically*; Böhm, Eggert, Barkmann, & Bögeholz, 2016).

Since these latter dimensions comprise the act of making a decision, they can be associated with the selectional phase of decision-making (Betsch & Haberstroh, 2005a; Bögeholz, 2007). The post-selectional phase, which is not further expanded as part of the model, encompasses the implementation of the final decision (Eggert & Bögeholz, 2006).

Similar to Fang et al. (2019), socioscientific decision-making according to the Göttinger competence model is framed as a multi-phased, individual, and mostly cognitive process. It portrays students as capable social actors, able to make informed decisions to actively shape the future of society (i.e., *Gestaltungskompetenz*[3]; Bögeholz, 2016; Haan, 2010)

2.2.4. Argumentation as a central aspect of decision-making

Argumentation permeates the entire decision-making process: It ranges from evaluating the provided information and different courses of action (pre-selectional phase and selectional

[3] *Gestaltungskompetenz* describes students' skills and knowledge to address and solve sustainability-related issues in order to guide changes in society. *Gestaltungskompetenz* encompasses twelve sub-competencies. For more details see Haan (2010).

phase) to justifying the final decision (selectional phase and post-selectional phase; Acar et al., 2010; Walton, 2006; Zeng et al., 2018). Elaborate argumentation skills, therefore, provide a "foundation for effective decision-making, helping decision-makers to better define and justify choices, thus engaging the decision-maker in more thoughtful processing of options and consequences" (Udell, 2007, p. 342). As a result, students' argumentation skills play a significant role in the context of socioscientific decision-making (Acar et al., 2010; Jiménez-Aleixandre, 2002).

Argumentation describes a form of goal-directed discourse which targets the (re-)construction of knowledge (Ford, 2008; Osborne & Patterson, 2011). Contrarily to the process of reasoning, which characterizes an *internal* negotiation, the process of argumentation *externalizes* (i.e., communicates) these previous considerations (Fischer et al., 2014; Means & Voss, 1996; Mercier, Boudry, Paglieri, & Trouche, 2017; Sadler & Zeidler, 2005). There are two different types of argumentation that have both become well-established research interests among the science education community (e.g., Dawson & Carson, 2020; Evagorou, Jiménez-Aleixandre, & Osborne, 2012; Faize, Husain, & Nisar, 2018; Jiménez-Aleixandre & Erduran, 2008; Simon, Erduran, & Osborne, 2006; Zohar & Nemet, 2002).

The first type of argumentation, *scientific argumentation*, describes students' use of scientific knowledge to construct and critique evidence-driven arguments which, in turn, aim to add to controversies that emerge *within* the science classroom (Erduran, Simon, & Osborne, 2004; Ford, 2012; Jiménez-Aleixandre & Erduran, 2008; Sampson & Clark, 2008). This first type is closely aligned with Vision I scientific literacy and presents argumentation as a scientific practice used to develop scientific ideas (see also Driver, Newton, & Osborne, 2000). The predominant research interest focuses on students' abilities to construct valid and robust arguments by utilizing different components of an argument (i.e., data, warrant, qualifier, rebuttal, and claim). The quality of an argument is thus examined on a *structural* level (e.g., Toulmin's Argument Pattern; Toulmin, 1958).

The second type of argumentation that is of interest to the science education community considers *socioscientific argumentation*. Socioscientific argumentation concerns students' successful participation in science-related social debates *outside* the classroom (i.e., SSI; Asterhan & Schwarz, 2016; Kolstø, 2001). In contrast to scientific argumentation, this second type of argumentation includes normative considerations (Mittelsten Scheid, 2009). Scholars that have been interested in the development of students' socioscientific argumentation predominantly focus on the content and reasons presented within the arguments (e.g., Christenson, Chang Rundgren, & Zeidler, 2014; Jiménez-Aleixandre & Brocos, 2017). Since SSI represent open-ended problems, the respective debate is characteristically dominated by diverse interest groups (Sadler, Barab et al., 2007; Sadler & Zeidler, 2005). As a result, the content and reasons provided within students' argumentation are often subject to a variety of perspectives. The SEE-SEP model by Chang Rundgren and Rundgren (2010) is an exemplary analysis framework for socioscientific argumentation that evaluates students' abilities to address this multi-perspectival complexity of SSI particularly well.

> ***Take-away definition for argumentation:*** *Students' argumentation skills encompass the purposive compilations of previous considerations (1) to contribute to evidence-driven controversies within the science classroom (scientific argumentation) or (2) to partake in scientifically and ethically complex debates that occur beyond the classroom walls (socioscientific argumentation). The latter type of argumentation explicitly stresses the inclusion of students' normative considerations and is of particular relevance within this work.*

2.2.5. Summary of Chapter 2.2

As a result of ongoing developments in science and technology, many of the most pressing societal questions nowadays represent SSI. For informed participation, students must be able to negotiate these issues by engaging in socioscientific decision-making (see also Kolstø, 2001). Socioscientific decision-making describes a cognitively complex and multi-phased process that entails students' consideration of different viewpoints and dimensions. Furthermore, students' argumentation constitutes a core component throughout the socioscientific decision-making process. Due to its societal importance, socioscientific decision-making was integrated into the German science education standards as an independent competence area (e.g., KMK, 2005a). To support and assess students' development in this respect, the Göttinger competence model for socioscientific decision-making in sustainability-related issues has been presented as one of the most prominent models on a national level.

2.3. Situating socioscientific decision-making

The previous chapters introduced socioscientific decision-making as an essential prerequisite for students' participation in societal debates that revolve around SSI. The negotiation of SSI, in turn, has been frequently documented in its potentials to promote students' socioscientific decision-making (e.g., Emery, Harlow, Whitmer, & Gaines, 2017; Gresch et al., 2013; Lee, 2007; Sadler & Zeidler, 2005).

Throughout the years, a large variety of SSI have been employed for research purposes to explore and enhance students' socioscientific decision-making. This heterogeneity of issues includes, for instance, environmental problems (e.g., Evagorou et al., 2012; Morin, Simonneaux, Simonneaux, & Tytler, 2013), genetic engineering (e.g., Walker & Zeidler, 2007; Zohar & Nemet, 2002), nuclear power (e.g., Jho et al., 2014), the use of animals for human entertainment or scientific development (e.g., Agell, Soria, & Carrió, 2014; Hößle & Alfs, 2014), and climate change (e.g., Dawson, 2015; Dawson & Carson, 2020).

For the work presented within this dissertation, two biology-related learning contexts have been designated: *Sustainable development* and *animal testing*. Each of the issues presents unique entry points for students' socioscientific decision-making. Animal testing, for example, concerns the use of living organisms for experimental purposes (Exner et al., 2004). Topics that surround the well-being of animals have been found to arouse students emotionally (Holstermann, Grube, & Bögeholz, 2009). This affective component, in turn, can evoke students' emotive resources which might further encourage their involvement in the respective discourse (see also Hidi & Renninger, 2006). Sustainable development, on the other hand, constitutes a debate that offers students numerous opportunities to translate their decisions into action (e.g., recycling, change of energy provider, green consumption choices). These small-scale but immediate possibilities for action can help students to reflect upon sustainability in practice, instead of merely in theory, and potentially motivate a more in-depth engagement with the issue (see also Pike et al., 2003).

Both issues will be introduced more thoroughly in the following. For structuring reasons, the characteristics for suitable SSI provided by Stolz et al. (2013; see Chapter 2.1.2) will be employed. These include (a) authenticity and relevance for students, (b) the issue's controversial features, and (c) its scientific and ethical aspects. In addition to these points, the issue's (d) prominence in science education will be addressed.

2.3.1. Sustainable development

Authenticity and relevance for students:

The global warming of our planet illustrates one of the most significant challenges facing today's societies. The rise in surface temperature increases the probability of, for example, extreme weather events, such as heatwaves and heavy rain in several regions across the planet (IPCC, 2018). Such consequences will be a severe threat to life on Earth and "of immediate relevance to young people in the near future" (White, 2011, p. 14). Sustainable development describes a concept that strives to counteract such developments to meet "the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Commission, 1987, p. 43). To protect the well-being of today’s and future generations, it is essential to support students’ abilities to make sustainable and informed decisions (Gresch & Bögeholz, 2013; Olsson, Gericke, & Chang Rundgren, 2015).

Controversial features:
There are four dimensions underpinning the concept of sustainable development: Environmental, social, economic, and cultural sustainability (Burford et al., 2013; Hawkes, 2001; Sartori, Da Silva, & Capos, 2014). These dimensions are inextricably interconnected and sustainable development strives simultaneously for environmental protection, economic prosperity, social equity, and well-being (Kelly, Sirr, & Ratcliffe, 2004). The negotiation of sustainability-related issues is therefore complex and often engages multiple stakeholders, which often hold conflicting interests (see also Bawa & Seidler, 2009).

Scientific and ethical aspects:
Participating in sustainability-related discussions can cause difficulties among students because they are often both factually and ethically complex (Eggert, Nitsch, Boone, Nückles, & Bögeholz, 2017; Jickling, 1992). To stem further global warming, for example, requires decisions that are based upon scientific knowledge, such as knowledge about the Earth’s climate system (e.g., Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009) and a precise understanding of the energy concept (e.g., Besson & Ambrosis, 2014; Mittenzwei, Bruckermann, Nordine, & Harms, 2019). On the other hand, sustainable development strives to meet the needs of present and future generations. An ethical dimension which targets the intra- and intergenerational justice, as well as the equity between humankind and nature, must be equally evident to the discussion (Langhelle, 1999).

Prominence in science education:
The role of education (formal, non-formal, and informal) has been widely acknowledged for the realization of a sustainable development (e.g., Little & Green, 2009; Vare & Scott, 2007). In the particular field of science education, the complexity underneath sustainability-related issues has often been stressed as fruitful for the exploration and enhancement of students’ socioscientific decision-making (e.g., Dawson & Carson, 2020; Eggert & Bögeholz, 2010; Gresch et al., 2013). In addition, the negotiation of sustainability-related issues can encourage students to develop and implement socio-political actions (Bencze, Sperling, & Carter, 2012). However, resulting from the same complexity, a great number of young people lack an adequate understanding of how to make well-informed decisions concerning sustainability-related issues (Collins et al., 2007; McBeth & Volk, 2009). More research should focus on how to support students in their sustainability-related decision-making.

2.3.2. Animal testing

Authenticity and relevance for students:

The term animal testing refers to any scientific experiment that takes advantages of living animals. These procedures can be associated with pain or damage for the animal in use (Exner et al., 2004). The scientific and medical advancements that have been achieved as a result of animal testing immensely affect our quality of life. Vaccines, for example, can help to prevent the spreading of diseases and the development of highly effective drugs can combat illnesses (see also Dietrich, 2017). The controversy about animal testing might be a familiar and meaningful issue to students: The recent release of undercover footage from animal testing laboratories in Germany (Hamburg), the Netherlands (Rijswijk), and the USA (New Mexico) provoked a public debate that mostly critiqued the prevailing conditions and practices inside animal testing laboratories. Contrarily, the use of animal testing for the development of a vaccine has received wide agreement in view of the COVID-19 pandemic.

Controversial features:

Even though the guidelines and principles connected to the procedure of animal testing are well defined (e.g., Tierschutzgesetz [German animal protection act]), there is no clear-cut consensus, neither within the scientific community nor the wider public, about its usefulness and, therefore, justifiability (Abbott, 2010). Strongly emotionalized opinions polarize the respective debate, ranging from strict rejection to ultimate acceptance of animal testing (Exner et al., 2004; Perry, 2007). As a result, there seems to be no general solution to this dilemma[4].

Scientific and ethical aspects:

Animal testing is an issue that well illustrates the inevitable interweaving of scientific practices and ethical considerations. On the one hand, animal testing can constitute a way to gain scientific insight into how therapeutic interventions, for example, interact with living bodies (DFG, 2016). Yet, to understand and critique the value that is often ascribed to animal testing, students need at least basic scientific knowledge (e.g., on genetics: Transferability of data obtained from mice to humans). On the other hand, students must also be able to reflect upon the ethical implications that are associated with animal testing. As aforementioned, research involving animals can have a severe effect on the animals' welfare, might cause suffering, and often ends with their killing once the experiment is completed (Nuffield Council on Bioethics, 2005).

Prominence in science education:

Animals play a significant role in scientific research (e.g., animal testing) and the science classroom (e.g., dissection practices, stuffed animal collections, classroom pets). However, animals have received little attention in the science education literature (Mueller, Tippins, & Stewart, 2017). A few studies that investigate students' general interest in animal testing

[4] A dilemma describes a decision situation with several possibilities for action; however, none of these possibilities can fulfil all moral requirements (Löschke, 2015).

have been conducted (e.g., Agell et al., 2014; France & Birdsall, 2015). The study by Agell and colleagues (2014) initiated a role play with students to discuss the usefulness of animal testing. Their results reveal the potentials of this issue to engage students in a meaningful debate. Yet, even though the relevance of animal testing for the individual as well as the broader society has been outlined above, a great number of students experience difficulties to discuss their viewpoint in the respective debate (Dias & Guedes, 2018). More research should focus on how to support students in negotiating their point of view in this SSI.

2.3.3. Summary of Chapter 2.3

With a growing interest in students' socioscientific decision-making and the potentials of SSI for science education, a great range of SSI have been utilized for science education research purposes in recent decades. This chapter presents *sustainable development* and *animal testing* as two biology-related SSI that can be particularly meaningful to students. Both issues also fulfil all the necessary criteria to be advocated for an implementation within science education (see also Stolz et al., 2013) which further supported the decision to choose these issues as learning contexts within this dissertation. Finally yet importantly, the aim of this dissertation was *not* to compare both issues in their effectiveness but to appreciate their individual potentials.

2.4. Four challenges related to students' socioscientific decision-making

The previous chapters outlined students' socioscientific decision-making as an essential component of scientific literacy. This chapter will focus on four potential challenges associated with the promotion and the assessment of students' socioscientific decision-making. These obstacles refer to: (1) the structure of the learning environment, (2) the complexity of SSI, as well as (3) the conceptualization and (4) the assessment of socioscientific decision-making. The first two challenges deal with the implementation of SSI for the promotion of socioscientific decision-making and thus address a teaching-learning perspective. The latter challenges focus on the structure and operationalization of socioscientific decision-making and are thus of particular interest to the science education research community (measurement perspective).

2.4.1. The teaching-learning perspective

The term SSI refers to compelling, science-related problems that are controversially debated within society (Fleming, 1986; Sadler, 2011). A major aim of their implementation is to authentically connect with students' personal life (Zeidler & Keefer, 2003). However, the structure of the learning environment (see Chapter 2.4.1.1) and the complexity of SSI (see Chapter 2.4.1.2) can display two challenges for the promotion of students' socioscientific decision-making in this respect.

2.4.1.1. The structure of the learning environment

Using SSI has been widely recognized as a means to promote students' socioscientific decision-making among both science education practitioners and the respective research community (e.g., Chung, Yoo, Kim, Lee, & Zeidler, 2016; Owens, Sadler, & Zeidler, 2017; Pope, 2017; Saunders & Rennie, 2013). This general agreement supports the assumption that SSI have an established standing within the science classroom. Yet, as revealed in a study by Lee, Abd-El-Khalick, and Choi (2006), there is a severe mismatch between teachers' perceived importance to implement SSI and their instructional behavior. While the survey answers of 86 South Korean science teachers suggest that they largely acknowledged the necessity to implement SSI during their science lessons, a closer analysis of the subsequent interview data revealed that "only a minority dealt with such issues in their classrooms and then only sporadically" (p. 97). Such a discrepancy between science teachers' verbal endorsement of SSI and their actual classroom instruction has also been observed in other international studies (Levinson, 2004; Pedersen & Totten, 2001; Reis & Galvao, 2004). Concluding from these observations, the assumption that there must be some kind of obstacles that impede the introduction of SSI has received great attention in the last couple of years (e.g., Dunlop & Veneu, 2019; Lee & Witz, 2009).

Thirty-seven science teachers took part in a study by Pedersen and Totten (2001), which aimed to inquire about these obstacles. One of the main institutional constraints that has been mentioned by participants of their study was the lack of support by other teachers and the faculty. Instructional obstacles that were frequently noted by other science teachers who took part in studies with a similar research aim included the lack of sufficient instruction time and inadequate teaching materials (Ekborg, Ottander, Silfver, & Simon, 2013; Lee et al., 2006).

The restructuring efforts associated with the implementation of SSI (see Chapter 2.1.4) can be challenging for both students and teachers (Ekborg et al., 2013; Lee et al., 2019; Lindahl, Folkesson, & Zeidler, 2019). This might explain why “the dominant model for secondary science education retains many features characteristic of what is widely referred to as a ‘traditional approach’” (Sadler, 2009, p. 7). Resulting from students’ more passive role in traditional classrooms, there seems to be only limited opportunity for them to engage in discourse and decision-making as part of their science learning experience (Driver et al., 2000; Duschl & Osborne, 2002; Osborne & Collins, 2001).

Even if all the above mentioned obstacles were overcome, there would still be another problem with students’ socioscientific decision-making. To prepare students for the social discourses outside school is one of the main goals of SSI education (Sadler, 2009). However, almost all SSI that are implemented within the science classroom are based upon fictional scenarios. In most cases, students’ socioscientific decision-making therefore remains hypothetical (Zeidler et al., 2019). Conclusively, the classroom-based negotiations of SSI often seem stuck in an academic scheme failing to engage students in real-world action (Zeidler, 2014; Zeidler et al., 2019). From this the question arises whether or not classroom-based decision-making experiences are capable of replicating societal debates (see also Levinson, 2013).

Conclusion: The structure, practices, and perceptions connected to the regular science classroom have been outlined as a challenge that can potentially impede the implementation of SSI and thus the promotion of students’ socioscientific decision-making. More research seems needed that investigates the potentials of additional, stimulating, and less rigorous science learning environments for the promotion of socioscientific decision-making: Extracurricular learning activities (see also Falk, Storksdieck, & Dierking, 2016).

2.4.1.2. The complexity of SSI

The conclusion of the previous section suggests investigating the potentials of extracurricular activities for the promotion of students' socioscientific decision-making. Yet, as critically noted in a study by Brown and Evans (2002), not all students have equal access to extracurricular learning activities. As a result, some of the students have more difficulties than others to explore their decision-making processes in the context of additional learning opportunities. Pressing SSI such as the current COVID-19 pandemic require informed behavior of *all* students. Consequently, it must be assured that *all* students have access to the necessary resources. Learning opportunities that are located within the regular classroom activities can respond to this demand. Despite the number of barriers mentioned in the previous chapter (see Chapter 2.4.1.1), supporting socioscientific decision-making as part of the regular science classroom seems, in light of this argument, more important than ever.

One concern that will be singled out within this section relates to the inherent complexity of SSI (see Chapter 2.2). Several studies thoroughly documented students' struggles to unravel this complexity in order to conclude an informed view or decision (e.g., Evagorou et al., 2012; Nielsen, 2012; Simon & Amos, 2011). In a study by Evagorou and colleagues (2012), for example, participants showed severe difficulties to acknowledge contradictory perspectives and neglected to involve multiple viewpoints into their socioscientific discourse. Resulting from such single-sided considerations, students might overlook the interconnectedness of the issue while negotiating on a superficial level. While extracurricular learning opportunities usually offer students an easier time schedule to untangle this complexity, the limited processing time provided in regular classroom settings might be an impeding factor that should not be underestimated in this respect (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006).

Resulting from this concern, more research should focus on the choosing of suitable issues for teaching. Suitable SSI could be issues that engage students in socioscientific discourse without requiring too much prior familiarity thereby making them less time consuming. Furthermore, additional research is needed to examine different conditions (e.g., issue familiarity) that help students to unravel the complexity of the SSI under debate.

Conclusion: The second challenge concerns the natural complexity of SSI which needs to be untangled by students in a relatively short period of time (often no longer than 90 minutes for a regular classroom hour). More research seems needed to identify (a) SSI that can be implemented by teachers as part of their regular school hours and (b) beneficial conditions that help students to engage in the underlying complexity of the issue.

2.4.2. The measurement perspective

Since the conceptualization and the assessment of socioscientific decision-making are closely interconnected with each other, these two challenges will not be introduced separately (see also Pellegrino, 2012).

2.4.2.1. Conceptualization and assessment of socioscientific decision-making

At the turn of the millennium, the newly established German national educational standards for science education introduced socioscientific decision-making as one of the four independent competence areas (Hostenbach et al., 2011; KMK, 2005a, KMK, 2005b, KMK, 2005c). At the same time, associated learning outcomes provided a need for new assessment instruments to benchmark students' achievements and to ensure high-quality teaching (Bernholt et al., 2012; Neumann, Bernholt, & Nentwig, 2012). While this research endeavor has been a major concern for the national educational research community in the past 15 years, it has not been without challenges.

The conceptualization of socioscientific decision-making, in a first step, lays the foundation for the subsequent operationalization (see also National Research Council, 2001). In contrast to the other competence areas, socioscientific decision-making illustrates a fairly novel area within the German context (Bernholt et al., 2012). Previous work which could have provided a basis for the operationalization and thus the design of suitable assessment instruments was, most likely, limited. In addition, the multi-phased and open-ended nature of socioscientific decision-making has been described as more sophisticated to measure than, for example, 'right-or-wrong' knowledge tests (e.g., Eggert & Bögeholz, 2010; Romine et al., 2017; Sadler & Zeidler, 2009).

Broader critique has been directed towards initiatives that align with the idea of progressive science education, such as the SSI movement. While possible learning outcomes connected to the progressive approach are appreciated, the shortage of adequate and authentic assessment instruments has been criticized (Orpwood, 2001; 2007). A possible explanation for this shortage targets the theoretical underpinnings of the SSI movement. According to Sadler and Zeidler (2009), as well as Zeidler et al. (2005), the SSI framework is primarily thought to inform instruction in order to support students' cognitive and moral development. To translate these pedagogical aims into assessment items is no easy task; contrarily, "student assessment may be a key challenge to the uptake of socioscientific teaching activities" (Tidemand & Nielsen, 2017, p. 46).

Conclusion: The conceptualization and assessment of socioscientific decision-making has been a major concern for the science education community. However, addressing these two challenges will not only be of interest to the science education community from a measurement perspective, because more insight "will then also be helpful to support and encourage teachers to integrate these topics into their science classroom" (Eggert & Bögeholz, 2010, p. 231).

2.4.3. Summary of Chapter 2.4

The four identified challenges concern (1) the structure of the learning environment, (2) the complexity of SSI, as well as (3) the conceptualization and (4) the assessment of socioscientific decision-making[5]. Whereas the first two challenges can be ascribed to a teaching-learning perspective, the latter two are assigned to a measurement perspective. Both perspectives are assumed to influence each other: New research insights can influence the design of interventions to support teachers in their practice. Vice-versa, teachers can enable researchers a valuable insight into the practicability of learning environments and students' experiences with socioscientific decision-making. Figure 2.4 illustrates these relationships.

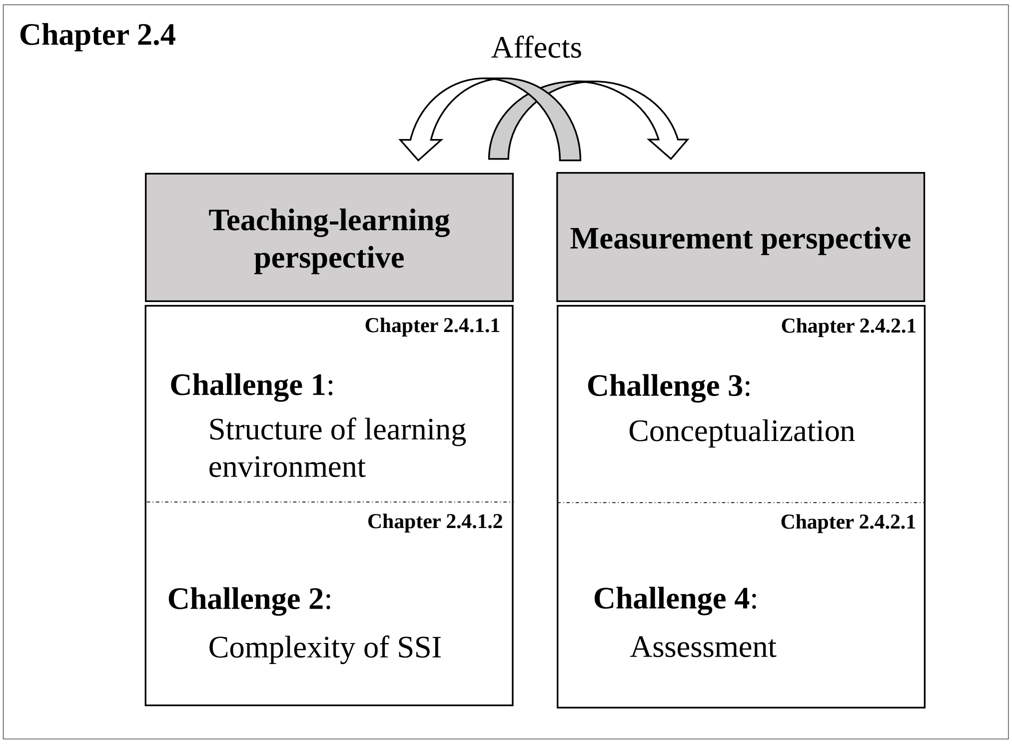

Figure 2.4: Four challenges that are connected to the promotion and assessment of students' socioscientific decision-making.

[5] The conceptualization of a competence and its assessment are tightly intertwined (see also Pellegrino, 2012). Changes in the construct (*what* needs to be assessed) eventually lead to changes in the assessment (*how* does it need to be assessed). Sometimes, in explorative studies, the *how* is used to determine the *what*. In the field of science education, however, this dynamic interrelation often begins with the *what* (conceptualization of a competence; see also Schecker, 2012). Within this dissertation, the conceptualization therefore constitutes Challenge 3 and the assessment encompasses Challenge 4.

3. AIM AND OVERVIEW OF THE STUDIES

Although socioscientific decision-making constitutes one of the four central competence areas of German science education and is further acknowledged as an important component of students' scientific literacy, four challenges have been identified that can be associated with its promotion and assessment. The four challenges can be summarized into two overarching categories: A teaching-learning perspective (Challenge 1 and Challenge 2) and a measurement perspective (Challenge 3 and Challenge 4). The present dissertation aims to expand the existing body of work by approaching these challenges over the course of three independent studies. To organize these studies, two structuring elements will be introduced in the following. First, the three studies can be structured along the four challenges. This displays the fundamental framework which will guide this dissertation in the following (see Table 3.1).

Table 3.1: The three conducted studies of this dissertation associated with the four identified challenges.

Framework / Studies	**The four identified challenges connected to students' socioscientific decision-making**			
	Challenge 1	*Challenge 2*	*Challenge 3*	*Challenge 4*
Study 1	**X**			
Study 2	**X**		**X**	**X**
Study 3		**X**		

Secondly, in order to make this dissertation's work connectable on an international level, the three studies can also be integrated into an overarching framework that was developed within the wider science education community. Therefore, Table 3.2 integrates each of the studies into the internationally established SSI framework by Zeidler et al. (2005; see Chapter 2.1.3).

Table 3.2: The three conducted studies of this dissertation integrated into the SSI framework by Zeidler et al. (2005). Each of the studies addressing at least two areas of pedagogical importance.

Framework / Studies	**The SSI framework with four areas of pedagogical importance**			
	Nature of Science issues	*Classroom discourse*	*Cultural issues*	*Case-based issues*
Study 1		**X**		**X**
Study 2			**X**	**X**
Study 3		**X**	**X**	**X**

The following sections briefly introduce the rational of each study. For an overview, Table 3.3 will summarize the main information of each study at the end of this chapter. This dissertation project has been further supported by three master thesis projects (for more information see Chapter 11.1).

Study 1 (Chapter 4): Students' decision-making in education for sustainability-related extracurricular activities – A systematic review of empirical studies

Sustainable development describes a key concept to assure a healthy and just living on planet Earth today and in the future. To live more sustainably, however, is no easy endeavor. To make informed and sustainable decisions is a complex yet necessary process to promote sustainable action. To date, many students show an inadequate understanding of how to make informed decisions in sustainability-related SSI. This raises the question regarding suitable learning environments that support students' sustainability-related decision-making adequately (*Challenge 1*). The first study explores extracurricular activities as advantageous learning format (participatory, interdisciplinary, and less rigorous) for students' socioscientific decision-making in sustainability-related SSI.

To shed light on the potentials of extracurricular activities for the promotion of students' sustainability-related decision-making, the first study conducted a systematic literature review. Data were collected from three electronic databases using individually developed syntaxes. In total, 367 articles were obtained. After the application of previously defined exclusion criteria, 19 studies could be identified for the final analysis.

Study 2 (Chapter 5): Fostering students' socioscientific decision-making – Exploring the effectiveness of an environmental science competition

The results from Study 1 indicate that extracurricular learning opportunities with sustainability-related focus can pose a suitable learning environment to foster students' socioscientific decision-making. This evidence was aimed to be validated in a second, empirical study (Study 2). The learning environment, which provides the setting for Study 2, is a project-oriented, environmental science competition (BundesUmweltWettbewerb; BUW). The BUW invites students from all over Germany to elaborate on sustainability-related issues, to investigate underlying socioscientific processes, and to carry out practical solutions. The competition uses an inquiry-based learning approach, which requires participants to make sensible decisions throughout their participation.

Continuing the research interest of Study 1, Study 2 assessed the BUW in its effectiveness to promote participants' socioscientific decision-making in two successive sub-studies. The first sub-study applied a paper-pencil test in a quasi-experimental repeated measures design with a control group. In total, 196 students took part in the first sub-study. Eighty-one of these students took part in the BUW 2017/2018 constituting the study's treatment group. In a second sub-study, 10 of the BUW-participants from sub-study 1 took part in retrospective interviews. Both sub-studies aimed to provide deeper insight into students' decision-making processes in this particular learning environment (*Challenge 1*). In addition, the "assessment triangle" by the National Research Council (2001) served as a rubric to examine both instruments that have been employed within this study to provide some methodological notes (*Challenge 3* and *Challenge 4*).

Study 3 (Chapter 6): 'I wouldn't want to be the animal in use nor the patient in need' – The role of issue familiarity in students' socioscientific argumentation

SSI have been outlined as inherently complex and open-ended problems. Coming to an informed view thus requires students to consider and articulate the variety of perspectives underneath the issue. This makes SSI ideal for practicing multi-perspectival argumentation.

In contrast to Study 1 and Study 2, the third study focuses on the regular classroom, including the previously outlined obstacle of limited instruction time. The first aim of Study 3 was to examine whether animal testing presents an effective issue that enables students' engagement in multi-perspectival argumentation *without* prior issue familiarity. The second aim of Study 3 was to investigate the relationship between context familiarity and students' multi-perspectival argumentation. The third study, conclusively, aimed to contribute to a deeper understanding of students' dealing with the complexity of SSI during their negotiation process (*Challenge 2*). In total, 163 ninth and tenth grader at public secondary schools located in Northern Germany participated in this intervention study that was set in a repeated measures design.

Table 3.3: Overview of the three conducted studies.

Study 1 (Chapter 4)	
Publication:	**Garrecht, C**., Bruckermann, T., & Harms, U. (2018). Students' decision-making in education for sustainability-related extracurricular activities – A systematic review of empirical studies. *Sustainability, 10*(11), 3876.
SSI:	Sustainable development
Research question:	Is there any empirical evidence in the literature that decision-making is promoted through the integration of sustainability-related issues in extracurricular activities?
Challenge:	Challenge 1
Design and sample:	Systematic literature review on basis of: • Three electronic databases: *Education Resources Information Center* (ERIC), *Web of Science* (WoS), and *FIS Bildung* • Full sample: *n* = 367 articles • Final literature collection for review: *n* = 19 articles
Methods and instruments:	Identification and selection of articles: • Cochrane Handbook for Systematic Reviews of Intervention (Higgins & Green, 2011) • Preferred reporting of items for systematic reviews and meta-analyzes statement (PRISMA; Moher et al., 2015; Moher, Liberati, Tetzlaff, & Altman, 2009) • Individual syntaxes for each database (e.g., ERIC: "out-of-school" OR "non-formal learning" OR "informal learning" OR "extracurricular" OR "extended education" OR "outside school" OR "learning outside the classroom" OR "after-school" OR

	“enrichment”) +descriptor:("sustainable development" OR "sustainability" OR "education for sustainable development" OR "socio-scientific issue" OR "environmental") +abstract:("decision-making") -educationlevel:("higher education" OR "university" OR "early childhood" OR "postsecondary education" OR "pre-school" OR "adult basic education" OR "two year colleges" OR "early childhood education" OR "adult education" OR "preschool education" OR "kindergarten") • Critical Review Forms by Law et al. (2007) and Letts et al. (2007)
Study 2 (Chapter 5)	
Publication:	**Garrecht, C.**, Eckhardt, M., Höffler, T. N., & Harms, U. (2020). Fostering students’ socioscientific decision-making: Exploring the effectiveness of an environmental science competition. *Disciplinary and Interdisciplinary Science Education Research*, *2*(5), 1-16.
SSI:	Sustainable development
Research aims:	The aim of the article is to • Assess an intervention (BUW) in its effectiveness to promote students’ socioscientific decision-making in two sub-studies • Evaluate the applied instruments in the light of the assessment triangle (National Research Council, 2001)
Challenges:	Challenge 1; Challenge 3, and Challenge 4

Design and sample:	Sub-study 1:
	• Quasi-experimental repeated measures design with control group
	• *n* = 196 students (total)
	  ○ *n* = 81 participants of the BUW (treatment group)
	  ○ *n* =115 students served as control group
	
	Sub-study 2:
	• Mixed-methods explanatory design
	• *n* = 10 participants of the BUW from sub-study 1

Instruments[6]:	Sub-study 1: • 45-minute paper-and-pencil questionnaire on decision-making by Eggert and Bögeholz (2010) Sub-study 2: • 30-minute retrospective interviews (semi-guided, problem-oriented, and conducted individually) inspired by Paul, Lederman, and Groß (2016)

[6] More information about the instruments that have been applied in Study 2 and Study 3 can be found in the supplementary materials (see Chapter 11.2).

Study 3 (Chapter 6)	
Publication:	**Garrecht, C.**, Reiss, M. J., & Harms, U. (in preparation). 'I wouldn't want to be the animal in use nor the patient in need' – The role of issue familiarity in students' socioscientific argumentation.
SSI:	Animal testing
Research aims:	The aim of the article is to • Examine whether animal testing is an effective issue to enable students' engagement in multi-perspectival argumentation *without* additional context familiarity • Clarify the relationship between *additional* context familiarity and students' multi-perspectival argumentation
Challenge:	Challenge 2
Design and sample:	Quasi-experimental repeated measures design with control group • *n* = 163 ninth and tenth graders (attended either grammar or comprehensive schools in Northern Germany) • *n* = 106 of these students additionally participated in a teaching unit about animal testing to familiarize themselves with the issue (treatment group)
Instrument:	Two open-ended and issue-specific items (animal testing) along the lines of Christenson et al. (2014)

4. STUDY 1

Students' decision-making in education for sustainability-related extracurricular activities – A systematic review of empirical studies[7]

Abstract

Equipping students with the capability to perform considerate decision-making is a key competence to elaborate socio-scientific issues. Particularly in the socio-scientific context of sustainable development, decision-making is required for the processing of information and the implementation of sustainable action. In order to promote decision-making, extracurricular activities in education for sustainable development (ESD) offer a suitable format due to their multidisciplinary and more informal structure. The purpose of this literature review is therefore to analyze empirical studies that explore students' (1) decision-making in (2) ESD-related (3) extracurricular activities. Following the PRISMA guidelines a systematic search yielded 19 out of 365 articles, each of them addressing all three components. Despite the theoretical relationship, hardly any empirical enquiry is found examining the trinomial interrelation with an equal consideration of all components. Contrarily, we argue that each is positioned in favor for only one component with the others serving as a backdrop. It follows that the full potential of an equal distribution between all three foci has not been explored yet; even though integrating sustainability-related issues in extracurricular activities displays a promising learning opportunity to optimally foster students' decision-making. Instead, studies that concentrate primarily on decision-making as a quantitatively measurable competence were predominant.

Keywords: Decision-making; education for sustainable development; extracurricular activities

[7] This is the peer-reviewed version of the following article: Garrecht, C., Bruckermann, T., & Harms, U. (2018). Students' decision-making in education for sustainability-related extracurricular activities – A systematic review of empirical studies. *Sustainability, 10*(11), 3876. The final print version of this article is available at: https://doi.org/10.3390/su10113876.

4.1. Introduction

Decision-making is one of the central cognitive processes of human beings [1][8] constituting a key component in formal teaching and learning [2,3]. On a daily base, plenty of our decisions are made intuitively. Making these decisions is often unconscious, quick and justified in a post-hoc process [4]. Besides this subliminal decision-making, some decision situations require more conscious considerations. According to Kahneman [5], these are drawn from a second and deliberate system of decision-making processes where coming to a decision is rather informed and therefore cognitively demanding. Decision-making hereby describes a rational process which causes the selection of a favored option or course of action among multiple alternatives that are based on specific criteria [6]. The actual acting upon a decision has been outlined a as complex and manifold process (e.g. [7–9]). However, the substantial role that the initial decision is playing for the following behavior was outlined in a meta-analysis by Webb & Sheeran [10]. We therefore consider decision-making as a cognitive precursor to action and therefore do not examine the actual acting upon decisions within this paper. In the following, we argue that decision-making is required for students' processing of socio-scientific issues especially when these issues are connected to the field of sustainable development. We further unfold the argument that extended education offerings display a fruitful frame for the implementation and promotion of both, sustainability-related issues and decision-making.

Decision-making receives much attention in educational theory, practice and research. In the context of formal education, positive outcomes of shared decision-making are indicated for students on class and school level [11] as well as individual level [12]. Siribunnam, Nuangchalerm and Jansawang [12] showed that decision-making in the science classroom is prominently discussed on an individual student level. As such, decision-making in science education is described as students' ability to discuss issues from multiple viewpoints, whilst considering scientific data as well as underlying personal and societal values of each option, and to conclude informed decisions [13]. In the science classroom, decision-making is predominantly required to elaborate socio-scientific issues [14]. The term socio-scientific issue (SSI) refers to controversial themes that touch equally upon social matters and scientific content. Characteristically, these issues have no definite solution and contrarily offer multiple conceivable solution approaches [15–18]. Each SSI can thus be "informed by scientific principles, theories and data but cannot be fully determined by scientific considerations" [16] (p.4), because it likewise demands dealing with ethical implications [15]. Driven by this intersection of social and scientific elements, SSIs do not only matter to the scientific community but are equally of interest for the society in general. The hereby emphasized real-world reference offers the potential to make science content more relevant for students [19–22] and to prepare students for their acting as responsible citizens [23,24]. SSIs in the context of sustainable development (SD) have been widely recorded in their exploration and enhancement of students' decision-making [16,25–27]. This predominance seems reasonable, since fostering students' capability to

[8] The reference style used within Chapter 4 is in accordance with the journal's guidelines.

act and make decisions in the context of sustainable development appears to be a strongly favored competence according to student teachers [28]. In the context of SD, decision-making is needed to seize and solve issues such as the loss of biodiversity [29,30], climate change [31], ocean acidification [32,33], air pollution [34,35] and a rising use in chemicals [36]. These are only a few examples of multidisciplinary and manifold processes linked to globalization and technological growth posing complex and pressuring decision situations for today's and future generations [37]. Since sustainability, the framework to implement a sustainable development, is based on four pillars: environmental, social, economic and cultural sustainability [38–41], its nature can be described as multifaceted. In order to unravel this complexity for students, the provision of an appropriate and supporting approach in education, namely education for sustainable development (ESD), has been widely recognized [42]. The importance of an educational approach within this context has been underpinned by its explicit listing as an independent goal of the Sustainable Development Goals, seventeen goals that aim to advance a sustainable, joint and just life on earth [43]. The implementation of ESD has been shown to either directly or indirectly affect individuals' sustainability understanding [44], sustainability consciousness [45], and SD-related attitudes [46]. Within this ESD-context, decision-making can be described as the preceded transcription of the SD-concept into informed decisions which can lead, in a further step, to selected real-world actions [47]. Conclusively, decision-making is understood as a necessary competence in ESD for the processing and promotion of sustainable action. The teaching and learning through ESD is further characterized by (1) its level-crossing (i.e. pre-school to adult education), (2) instructional diverse compositions (formal, non-formal and informal) [37], and it is (3) understood as an approach rooting in various disciplines from humanities, natural sciences and social sciences [48]. Even though the school environment can constitute an educational platform to develop and apply ESD-actions in order to "promote the learning of skills, perspectives and values necessary to foster sustainable societies" [49] (p.226), we will put forward two arguments in favor for an embedding in extracurricular activities. Firstly, regular school hours are formally tied to their discipline-driven curriculum. These disciplinary barriers might be too narrow in order to examine a highly complex and transdisciplinary learning content such as SD [50]. Contrarily, "sustainable development teaching will be richest when pupils experience these elements […] in an integrated, non-fragmented way" [51] (p. 627). Secondly, regular school hours are commonly bound to formal requirements such as a rigorous temporal limitation, formal assessment and a tight interdependence with standards in national curricula [52,53]. Extracurricular activities, on the contrary, might pose a participatory, interdisciplinary and real-world-related learning context for the successful implementation of those ESD-actions [54,55]. In other words, detached from the clearly structured and assessment-focused schooling environment, extracurricular education allows to overcome structural boundaries and to implement an advantageous learning format for ESD [56]. With regards to ESD, the positive effect of extracurricular activities on students' knowledge and attitudes regarding sustainability and SD has been recorded in several studies [57–59]. Extracurricular activities are likewise perceived by teachers as valuable approach to foster competencies for citizenship such as decision-making [60]. In this understanding an activating component is ascribed to young people and they are thus perceived as able to act as “critical-democratic citizens” [61] (p.107). Commonly, extracurricular offerings are described as elective, additional and ungraded educational undertakings which are set inside the school facilities, but outside the regular school hours [62]. However, despite their supplementary and optional character many activities still fall within the scope of the curriculum and are closely linked to academic performance [62]. Aside from the academically-focused activities, their potential to “offer a means to express and explore one’s identity, generate social and human capital, and offer a challenging setting outside of academics” [63] (p.161) should be likewise discussed. The herby highlighted aspect of an extended area of influence is revisited in a much younger term acknowledged as extended education. Extended education can be understood as a particular form of extracurricular education, a form which is “usually subject to a low level of curricular requirement” [64] (p.8) and therefore suitable for multidisciplinary topics such as SD. For this paper’s research endeavor three main aspects are extracted from its definition: extended education includes the facilitation of (i) educationally structured and (ii) student-centered learning processes that are (iii) not part of the regular curriculum [65]. In order to further delimit what is understood as extended education within this paper, we will exclusively consider offerings that can be set in the wider school context [62].

4.2. Research questions and aims

On a generic level, decision-making has been outlined as a key competence for a participatory living in the 21st century. In the narrower context of formal education, this theoretical derivation highlighted decision-making as a central objective in science education playing a vital role in students’ processing of SSIs. Particularly SSIs that are set within the multifaceted nature of SD promote the development of decision-making and likewise foster students’ involvement, knowledge and attitudes regarding SD. As such, decision-making has been shown as valuable competence in the context of ESD. Within this ESD context, extended education activities have been represented as suitable stage offering a multidisciplinary and more informal learning context. In light of these theoretical underpinnings, we follow the argument that ESD-related extended education activities hence offer both, multifaceted problems and lower boundaries than formal education and are therefore a promising learning opportunity to promote decision-making. The exploration of this threefold overlap will thus be the main focus of the here presented systematic literature review (see Figure 4.1).

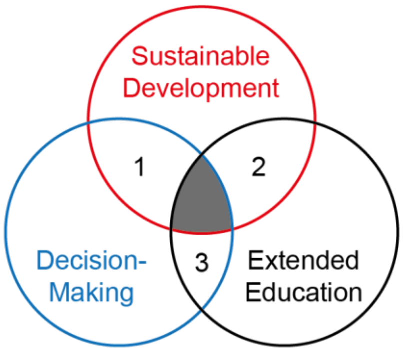

Figure 4.1: Graphical illustration of this paper's underlying research interest (grey space) combining (1) decision-making in sustainability-related issues (2) sustainability-related issues in extended education activities and (3) decision-making in extended education activities.

Within this review we aim to explore the intersection displayed in ESD-related extended education offerings addressing students' decision-making. As such, the paper predominantly lines up with topical studies examining the importance of students' decision-making in broader educational contexts (e.g. [66]) as well as its role in particularly sustainability-related education contexts (e.g. [67]). Yet, in more general terms, it also contributes to the discussion in the field of educational research informed by value-driven and interdisciplinary approaches such as ESD. The research question that will guide our systematic review is read as followed: Is there any empirical evidence in the literature that decision-making is promoted through the integration of sustainability-related issues in extended education activities?

4.3. Methodology

The systematic literature review was conducted according to the methodological guidelines in the Cochrane Handbook for Systematic Reviews of Interventions [68]. Furthermore, the procedure of identification and selection of relevant articles was guided by the preferred-reporting of items for systematic reviews and meta-analyses statement (PRISMA; [69,70]). The resulting PRISMA flowchart illustrates the different phases of the selection process (see Figure 4.2) through reasoned inclusion and exclusion criteria (see Table 4.1). Data was collected from three electronic databases, two international ones and a German database, each fitting the interest of the underlying research endeavor: (1) *Education Resources Information Center* (ERIC), as an internationally recognized database for educational research, and (2) *Web of Science* (WoS), as a supplementary database focusing on scientific research to assure a holistic approach to the concept of sustainability. To encompass a German perspective we performed a separate search with German translations of the search terms in (3) *FIS Bildung*, the German equivalent to ERIC.

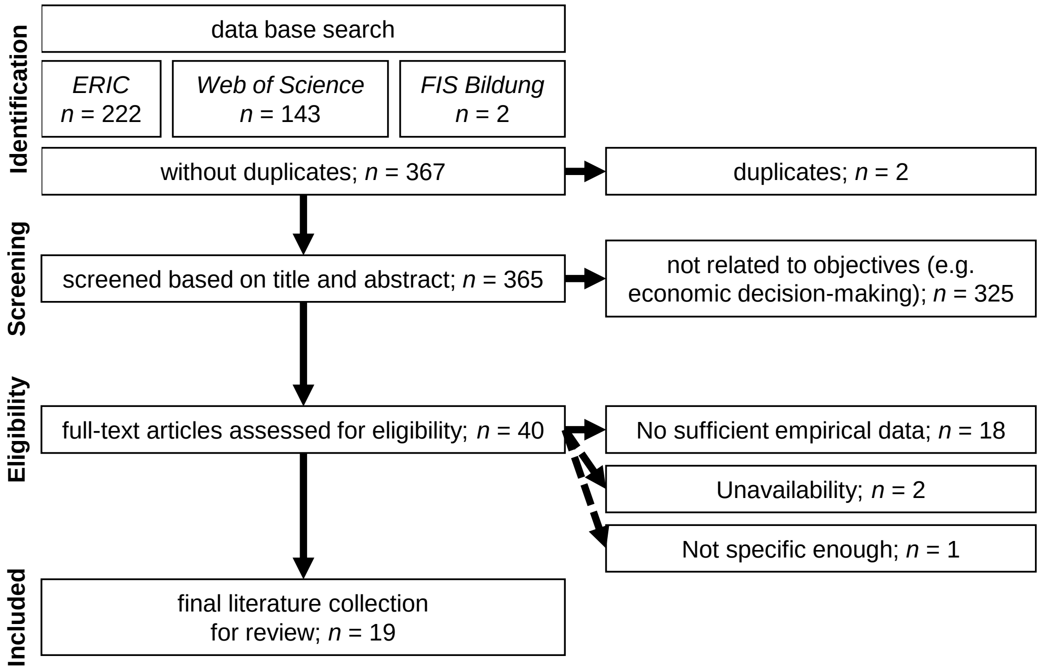

Figure 4.2: PRISMA flowchart of the article selection process.

The validity of results in a systematic literature review depends on the selection of search terms and databases. In order to establish the results' validity the three key search terms *extended education*, *sustainable development* and *decision making* were based on theoretical considerations and expanded with terms found to be used interchangeably in other peer-reviewed papers. Following this manner, the search terms were optimized to find all relevant papers without generating an unmanageable number of search results. The selection of databases accounted for discipline-general (WoS) and discipline-specific (ERIC, FIS) publications on an international (ERIC, WoS) as well as national level (FIS). Limits to the validity are discussed in the limitations section (see 4.5.2.). Individual syntaxes were developed and used for each database. For exemplary reasons one of the syntaxes is shown below.

ERIC on the fifth of December, 2017 (222 articles):

> ("out-of-school" OR "non-formal learning" OR "informal learning" OR "extracurricular" OR "extended education" OR "outside school" OR "learning outside the classroom" OR "after-school" OR “enrichment”) +descriptor:("sustainable development" OR "sustainability" OR "education for sustainable development" OR "socio-scientific issue" OR "environmental") +abstract:("decision-making") -educationlevel:("higher education" OR "university" OR "early childhood" OR "postsecondary education" OR "pre-school" OR "adult basic education" OR "two year colleges" OR "early childhood education" OR "adult education" OR "preschool education" OR "kindergarten")

The final database search was performed in December, 2017. In order to assure a sufficient quality, only peer-reviewed articles were included into this review [71]. In total, 367 articles were obtained containing two doubles. Thus, the search identified 365 unique articles. The abstracts (including keywords if used) of 365 articles were screened twice applying the beforehand defined exclusion criteria which were deductively drawn upon the definitions given in the theoretical background. In case of insufficient or vague abstracts the entire paper was browsed.

Table 4.1: Inclusion and exclusion criteria for the selection of relevant articles.

Criterion	**Inclusion**	**Exclusion**
Extended Education	Particular activities or methods to expand the regular curriculum inside or outside the classroom setting, school bound	Outdoor or environmental education offerings not related to the wider school context
Decision-making	Educational context	Economical context (e.g. PROMETHE strategy)
Sustainable Development	Activities addressing environmental, economic or social sustainable development with focus on individuals	Sustainable development with focus on institutions (e.g. policies)
Focus	Students	Teachers, parents, development of an instrument
Age	Primary to end of school	Kindergarten, university, adult education
Language	English and German	Other languages
Type of article	Peer-reviewed article displaying empirical data	Non-peer-reviewed article, article that displays no or poor empirical data

Using the criteria above, 40 of the 365 articles fitted the eligibility set of this research endeavor. Two papers [72,73] were not available despite requesting it through different platforms. Hence, 38 papers were analyzed within this literature review. These papers were read carefully and for several times by the first author of this paper and relevant data from each paper was extracted and filled into the Critical Review Forms designed by Law et al. [74] and Letts et al. [75], a form commonly used for systematic literature reviews (e.g. [76,77]). Hence, a rigorous and precise data collection of all 38 papers was assured. Furthermore, by using these standardized review forms the subjectivity during the selection and analysis process was minimized and reliability was enhanced. Using these review forms enabled us to detect studies of insufficient quality during an early stage and reduced the risk of analyzing the studies' results selectively. After this detailed examination, 18 studies could be eliminated based on their poor empirical data. This most frequently included the mere description of educational exercises and games (e.g. [78]). The final selection for this systematic literature review yielded 19 articles with a good overall quality and all of which are displaying an overlap of the three components drawn upon in the theoretical derivation. The corresponding table can be found in the appendix (see Table 4.2).

4.4. Results and discussion

All of the identified papers (*n* = 19) share a common intersection of the three components. This, in a first step, affirms evidence in the literature that there are studies that display the consideration of decision-making within ESD-related extended education activities. However, while analyzing each paper individually, a study-dependent and predominant concentration on one of the three components (either SD, decision-making or extended education activity) was noticeable. In other words, one of the three components was more central for the interest, course and results of the study than the others. Consequently, the results and discussion section of this review follows an analytical course by splitting the identified studies into three groups; whereas each of the groups is defined by their main emphasis. Furthermore, each group will then be presented with a focal point on decision-making, since all of the studies highlighted decision-making as a variable of interest. The analytical proceeding that we will follow within this section accentuates the assumption that comprehending each individual component is crucial in order to coherently understand the bigger picture [79]. However, we likewise want to acknowledge that "the whole is certainly more than the sum of its parts" [79] (p.165) which we want to emphasize through brief considerations regarding the component's interplay in the beginning of each paragraph. For a visibly distinction between identified articles and other references, the reference numbers of identified articles are marked by an asterisk.

4.4.1. Surface characteristics of the reviewed papers

The majority of studies was conducted in Europe (*n* = 13, Germany [80–84], United Kingdom [85,86] Cyprus [87,88], Israel [89], the Netherlands [90], Czech Republic [91], and Spain [92]), followed by studies from North America (*n* = 4, America [93–95] and Canada [96]). There was a scattering of studies from Asia (*n* = 1, Singapore [97]) and Oceania (*n* = 1, Australia [67]).

Most studies collected their data from students attending upper secondary education (*n* = 9 [67,80–82,84,86,87,92,93]). These students are typically 15 to 18 years old and in grade 9 to 12. Studies that were undertaken in lower secondary education (*n* = 7 [87–89,91,94–96]) comprised students aged 11 to 14 belonging to grade 6 to 8. One study was conducted in a primary school (*n* = 1 [85]) with children aged 7-12. There was also one study that had no information on the participants' age [90] and one study that conducted data from children belonging to upper as well as lower secondary education [97].

Half of the papers followed a qualitative research design (*n* = 9 [80,82,85,91,92,94–97]). Seven papers (*n* = 7 [83,86–90,93]) used a pre-post-test design with intervention and three articles (*n* = 3 [80,81,84]) chose a pre-post-follow up with control group test design.

4.4.2. Studies with a focus on decision-making – Decision-making as quantitatively measureable competence

Most papers (*n* = 14) predominantly object to model decision-making as a quantitatively measureable competence and therefore focus on decision-making as a competence itself. Within these papers sustainable development, as a thematic circumstance, and the specific integration within an extended education offering constitute the contextual framework. Nonetheless, for the studies' interest and design both components are of minor importance. In this group of papers, three major interests in decision-making were identified: (1) its development, (2) the assessment of its quality and (3) its inherent structure. The following statement stands exemplarily for papers with this focus: "Decision-making competence refers to the ability to systematically evaluate possible courses of action and […] to systematically make a final decision" [80] (p.734).

Papers with this focus (*n* = 14 [67,80–84,86–88,90,92–95]) define decision-making as a competence required in the process of reasoning. Derived from this perception as a competence, decision-making appears to be investigable in its structure and development. Resulting from this developmentally understanding, decision-making seems to be further assessable in its quality. These preliminary assumptions will be examined in the following.

The majority of papers within this subsection (*n* = 8 [80,81,83,84,86,87,90,93]) explores the effect of specific methods, strategies or approaches on the *development of decision-making*. Hereby, decision-making competence is described on a latent continuum with separate and differing levels [98]. Based on this separation into independent levels, and the possibility to develop from one level to the other, decision-making is handled as a measurable variable. Gresch, Hasselhorn and Bögeholz [84], for example, explore the effect of particular strategies on students' decision-making. Additionally, they investigate if aspects of self-regulated learning, implemented through the use of a computer-based training program, can assist this process. The results indicate that participants who received a training with elements of self-regulated learning show greater and sustained benefits regarding (1) the inclusion of metadecision aspects, such as structuring and planning the decision-making processes, as well as (2) the reflection on others' decision-making processes. From this illustrative study, where the development of decision-making is measured in turns of achieving higher competence levels, we can underpin our prior statement that decision-making is handled as a measurable variable. This understanding leads us to the aspect of assessment.

A few papers of this subcategory (*n* = 2 [67,82]) use pedagogical units to *assess the quality* of students' decision-making. The interventions presented in these articles are not aiming at the promotion of decision-making in the sense of reaching a higher competence level, but solely focus on evaluating its present quality. For instance, Belova, Eilks and Feierabend [82] use different types of role-play on climate change to evaluate students' quality of argumentation. They therefore rate each of the used arguments from the role-play in three main categories (domain, level and reference). In order to assess the quality of decision-making, their second category (level) describes the argument's complexity in gradual levels from zero (not related to the topic) to five (elaborated). While investigating their collected data through the application of each category, Belova, Eilks and Feierabend [82] were able to analyze each argument in detail. As a result of their study, they identified role-play as an opportunity to mimic societal debating and to assess decision-making in its inner quality. In formal education, tools for students' assessment are an essential for teachers since grading takes up an elemental part of their tasks [99]. This should not be taken lightly; the effect of grades on students' self-concept is already shown [100]. With regards to current findings from Steffen and Hößle [101] further research into the assessment of students' decision-making is needed. Concluding from their paper, teachers have trouble in diagnosing and evaluating students' decision-making and rather perform a negated coping. This means that teachers question their ability to diagnose decision-making even though their capability is confirmed [101]. Further assessment tools could therefore help practitioners to encourage and gauge students' decision-making and to purposively incorporate supportive activities into their lesson planning. That only two of the identified papers within this subcategory address the assessment of students' decision-making can be explained by this paper's underlying research interest. While we were particularly looking for extended education offerings, these are, in most cases, ungraded [65].

In contrast to the development or the quality of decision-making, some papers ($n = 4$ [88,92,94,95]) concentrate on its *structural composition*. Paraskeva-Hadjichambi, Hadjichanmbis and Korflatis [88], for example, are interested in the role of values and how these are interlinked when making decisions. In their perspective, the ability to prioritize different criteria and to expose the underlying values might be a suitable way to deal with SSIs. This assumption, that values pose an immanent element for the settlement of SSIs, is long-established [102] and several research practitioners are shedding the light on an ethical dimension within decision-making [103–106].

Concluding these deliberations, three major interests in decision-making were presented: (1) its development, (2) the assessment of its quality and (3) its inherent structure. Based on these interests, decision-making is understood as a measurable competence. Interestingly, in the identified papers of this subsection decision-making is presented as a practice that mainly takes place within an individual's cognition in the sense of a systematic proceeding. Questions regarding an explicit integration of others, for example through an evoked change in perspectives, remain open. Especially in the light of our globalized and multicultural society the explicit promotion of multiple perspectives appears necessary to foster a sustainable development [107].

4.4.3. Studies with a focus on extended education activities – Decision-making as participation in change

Some papers ($n = 3$) aim particular attention at the educational embodiment within which decision-making is explored. This means, the specific characteristics of the activity are setting the fundamental basis that enables a development of decision-making. Sustainable development is, again, providing the thematic context which could be ousted by another real-world, ill-defined and urging issue such as the use of animal research. In this group of studies the students' participation in change, which is offered through the facilitation of an extended education activity, was identified as main outcome with regards to decision-making. The following statement stands exemplarily for papers with this focus: "Rather than preparing for a life after school or for future science courses, children already participated in and contributed to social life in the community" [96] (p.273).

Three articles ([89,96,97]) focus on how the educational engagement in real-world problem-solving activities can empower students to make decisions and thus to get involved in civic matters. Here, the *educational context* of the extended education activity is *in the foreground*. The paper written by Roth & Lee [96], for instance, permits an insight into a case study developing a science education model that takes scientific literacy into the local community. Based on a 3-year, multisite ethnographic research project, the authors illustrate a "rethinking of science education" (p.263). Here, the students were required to get actively engaged in a local socio-scientific issue. After practicing scientific procedures inside the classroom, students conducted their own research in and along a creek's watershed. Students then presented their findings to other school classes and during an environmental event. In this sense, the educational content of water quality and related problems were broadened from the classroom into the real-world community context. During this problem-solving process the community was involved twofold: on one hand, they were actively involved by assisting students' research activities and on the other hand, they were also intertwined in a more personal way since water quality-related problems were an urging community concern.

In all three papers of this subcategory, the embodiment of the community and local places seems to be a joint feature. From an instructional perspective, this draws attention to an approach called place-based education. In place-based education the primary interest lies in the interconnectedness of local places, the community and educational activities [108]. The underlying pedagogical concept of place-based education can be traced back to John Dewey [109] who campaigned for an extension of methods in the back then contemporary education. In his understanding, educational experiences that are interwoven with the local environment enable students the connection of their academic and personal life. This accentuation on contextualized learning, where theoretical content can be associated with the personal life, remains the fundamental aspect of place-based education to this day [108,110]. Expanding this understanding, Gruenewald, Koppelman and Elam [111] spotlight an applied dimension of place-based education. In their deliberation, the inclusion of the local environment equally enables a centering of the human-nature relationship. Through the interaction with local places, and ergo their construction and destruction, students are able to experience the human impact on the environment. This experience, according to Gruenewald and Smith [112], can enhance students' participation in civic decision-making since places hereby create "contexts for the practice of democracy" [111] (p.235).

The identified papers of this subcategory highlight a further aspect worth discussing. Teaching within the context of sustainability and with the aid of teaching material is often interlinked with a simplification of the issue [113]. According to Holfelder [113], in simplified learning material students are commonly seen in a one-dimensional role of consuming individuals. In other words, students are perceived as individuals that can solely act upon existing processes and thus decide between different options of consumption (e.g. to buy fast-fashion or fair-trade clothes). Contrarily, in the identified papers of this subcategory decision-making goes beyond the request to merely choose between different options. Here, the relocation of a problem-solving task into a real-world community context through extended education activities adds an active dimension and can lead to a serious change on a civic and maybe even a political level. This promotes an understanding of students as active citizens shaping our society. According to Akin, Calik and Engin-Demir [114], the promotion of active citizenship through shared decision-making can further be regarded as essential to maintain and improve a democratic culture. This critical-democratic notion of citizenship supports students' enquiring attitude to creatively address pressuring and complex issues [61]. The promotion of such activating perceptions seems necessary for the enabling of a sustainable future [115].

4.4.4. Studies with a focus on the context of SD – Decision-making as empowerment

Two of the articles [85,91] deliberately set their research in the context of SD. The involvement with this particular context is understood as a potential stage that empowers students to express themselves. Without a steered learning goal, the *educational context* of the activity is located *in the background*. Rather than putting subject-based learning content across, the extended education activity within the ESD is understood as "space for transformative social learning" [116] (p.388). In this group of studies students' empowerment was recognized as chief finding with regards to decision-making. The following statement stands exemplarily for papers with this focus: "Another feature of education for sustainable development is the use of a learner-centered and democratic approach that empowers students to address real world issues." [85] (p.12).

The paper by Mannion [85] develops a typology that categorizes Scottish school students' involvement in decision-making processes and their resulting participation in a playground development. The typology reveals a wide-ranging perception of children's ability to engage in decision-making. This ranges from barely any participation, for example because of safety reasons, to great autonomy allowing them their private space separated from obvious adult supervision. Decision-making in both papers of this subsection is understood as children's empowerment to make their voice heard. Concluding from this, children are seen as serious members of the decision-making body and corresponding processes. This understanding, participation in decision-making as empowerment, is an integral part of ESD [117].

The authors' selection of qualitative research designs and explorative research instruments, in both papers, seems reasonable to holistically capture children's opinions and thoughts [118]. Despite that, it is highly important to consider that depending on the research question one might not measure an objective reality, but rather participants' construction of it. As an example, the paper by Cincera and Kovacikova [91] explores how students experience being a member of an environmental school group and how they reflect on their involvement. As noted by the authors, the collected data within this study does not display the actual working processes of the environmental program, but rather mirrors participants' subjective perception. Nevertheless, the direct participation in the discussion and solution of environmental issues through the involvement in the school's environmental group underlines, again, an enabling perception of students. This goes in line with James and Prout [119] who state that young people have to be seen as capable and responsible social actors with their own mind and voice. Especially in the context of sustainable development and related environmental, social and economic issues that will occur in the future, the serious recognition of later generations appears crucial [115]. Well-planned activities with a thematic focus on SD such as the environmental school group can hence be seen as a valuable opportunity to empower students as independent and capable actors willing to take responsibility for our future.

4.5. Conclusion

A goal of this study was to identify ESD-related extended education offerings and their contributions to students' decision-making. Using the search syntaxes, a total of 365 peer-reviewed journal articles were found in December, 2017. After skimming available abstracts and corresponding keywords, 38 full-text articles were evaluated for eligibility. The final selection yielded 19 articles for this systematic literature review. The common intersection of the three components: sustainable development, extended education offering and students' decision making is evident in all of the identified papers. This affirms the initial research interest in a common overlap in the existing literature. Nevertheless, an unequal distribution of the studies' research interests was noticed. Most papers particularly target decision-making, framing it as a quantitatively measurable competence. Here, three major interests in decision-making were identified: (1) its development, (2) the assessment of its quality and (3) its inherent structure. Studies that chiefly focused on the educational aspect, namely the extended education activity, highlighted the educational framework which is needed in order to enable the development of decision-making. In these papers, decision-making was understood as students' participation in change. In the last group of studies, concentrating on the component of SD, the specific theme was seen as a successful platform for students to use decision-making in order to express their thoughts and opinions.

4.5.1. The gap – Students' decision-making in ESD-related extracurricular education

Despite the papers' common area of interest, each paper can be positioned in favor for only one of the three components with the other components serving as a backdrop. Resulting from this observation, none of the papers seems to display an equal distribution of attention. This, however, needs to be viewed critically, because integrating sustainability-related issues in an extended education activity displays a promising learning opportunity to optimally foster students' decision-making. Up to date, questions concerning sustainable development are difficult to integrate in subject-based lessons [50]. Extended education activities have thus been argued to constitute a highly suitable and more holistic platform to process complex and multidiscipline topics such as SD [54]. The multidisciplinary character of sustainability-issues can hereby foster decision-making which is required when processing questions that pose complex and pressuring decision situations for today's and future generations [37].

The differing foci found instead might be explained by looking at the scientific origin of each component. Whereas extended education roots in the educational research sector [120], the concept behind decision-making has its origin in cognitive psychology [1]. Sustainability, in contrast, has its thematic core equally in the natural and social sciences due to its holistic and multifaceted nature [38]. A study displaying an equal distribution of all three components would accordingly require a balanced deliberation of diverse disciplines. In contrast to this multifacetedness, being a researcher is often equated with being an expert in a precise field. This circumstance might partly explain the lack of papers that are locatable in the joint center of the three components.

Although we put forward a strong theoretical argument for the integration of sustainability-related issues in extended education activities to promote decision-making, our literature review could not reveal any studies with empirical evidence for this argument. We therefore suggest further research to address this interrelation in order to support our argument empirically.

4.5.2. Limitations

A limitation of this review is its little contribution to the discussion concerning values and ethics; even though moral aspects are an acknowledged facet of decision-making. Retrospectively, we would suggest adding appropriate terms to the syntaxes, such as moral judgement, in order to ensure the identification of relevant papers. Furthermore, review articles are typically constraint by a publication bias. This means that research reporting statistically significant effects are more often published than papers reporting non-significant effects [121]. Writing a systematic review conclusively underlies the journals' pre-selection of articles. The conduction of a meta-analysis might have controlled this bias; nevertheless, since a large proportion of the papers are subject to a qualitative research design this endeavor did not seem suitable.

Apart from the mostly optional participation in early childhood education offerings, the national school system constitutes the baseline of collectively received education. As shown within this paper, besides the regular and compulsory school hours, extracurricular activities have become a valuable element of students' school life [122]. The development and support of decision-making is, nevertheless, also addressed through curricular activities. However, these studies were not addressed due to our interest in extended education activities and the subsequent development of specific search terms. We therefore want to acknowledge that much work that is done by other prominent research groups in the field of decision-making fell short in reference (e.g. [123–126]).

4.6. Implications

Further research value is seen in the conduction of studies that are set within the equal distribution of all three components, since it is assumed that promoting students' decision-making is optimally performed in ESD-related extracurricular activities dealing with interdisciplinary and socio-scientific issues such as SD. In addition, we assume that the exploration of decision-making's differing notions would be beneficial to gain further insight into its inherent construction. This includes the conceptualization as (1) a systematic process that chiefly takes place within the spectrum of personal reasoning (e.g. [98]) and as (2) a competence that explicitly embraces the consideration of other's values and perspectives (e.g. [125]).

For educational practice two main implications can be drawn upon this literature review. The first suggestion addresses the planning and implementation of learning activities. While advocating students to perform as critical citizens in ESD-related issues, practitioners equally need to provide an adequate educational context. This implication might be from structural nature such as allowing students the time and space to enquire self-chosen environmental, economic or social problems within their local environment. It might also imply acquiring new subject knowledge to jointly explore and discuss students' solution approaches. The empowerment of students' learning in ESD-related issues can thus transform practitioners themselves to agents of change [127]. Secondly, whenever learning activities are implemented, they are perceived within one's personal frame of reference [128]. Sustainable development can hereby operate as a doorway to modify these frames, since conflicting values, beliefs and interest can support a critical discourse amongst students [129]. Even though no empirical evidence has been found yet, we would like to encourage practitioners to implement ESD-related extracurricular activities in order to promote students' decision-making and a sustainable dialogue.

Education remains one of the key elements for civic partaking. Educational approaches, such as ESD, thus build a fundamental platform for the discussion and creation of ideas that lead to informed decisions and actions. We therefore want to emphasize the importance of ESD and connected activities, since this surely will be crucial for the maintenance of a well-functioning and open-minded society that is capable of dealing with environmental, social and economic challenges that lie ahead of us. In the end, students are the future's hope and we should try our best to equip them with competences to jointly decide for a more sustainable and just world.

4.7. References[9]

1. Wang, Y.; Ruhe, G. The Cognitive Process of Decision Making. *Int. J. Cogn. Inform. Nat. Intell.* **2007**, *1*, 73–85, doi:10.4018/jcini.2007040105.
2. Zeidler, D.L.; Sadler, T.D.; Simmons, M.L.; Howes, E.V. Beyond STS: A research-based framework for socioscientific issues education. *Sci. Educ*. **2005**, *89*, 357–377, doi:10.1002/sce.20048.
3. Stefanou, C.R.; Perencevich, K.C.; DiCintio, M.; Turner, J.C. Supporting Autonomy in the Classroom: Ways Teachers Encourage Student Decision Making and Ownership. *Educ. Psychol*. **2004**, *39*, 97–110, doi:10.1207/s15326985ep3902_2.
4. Haidt, J. The new synthesis in moral psychology. *Science* **2007**, *316*, 998–1002, doi:10.1126/science.1137651.
5. Kahneman, D. *Thinking, Fast and Slow*; Penguin: München, Germany, 2012.
6. Wilson, R.; Keil, F. *MIT Encyclopedia of the Cognitive Sciences*; MIT Press: Cambridge, UK, 2001.
7. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process*. **1991**, *50*, 179–211, doi:10.1016/0749-5978(91)90020-T.
8. Ajzen, I.; Fishbein, M. The Prediction of Behavior from Attitudinal and Normative Variables. *J. Exp. Soc. Psychol.* **1970**, *6*, 466–487.
9. Wood, W.; Quinn, J.M.; Kashy, D.A. Habits in everyday life: Thought, emotion, and action. *J. Pers. Soc. Psychol*. **2002**, *83*, 1281–1297, doi:10.1037//0022-3514.83.6.1281.
10. Webb, T.L.; Sheeran, P. Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. *Psychol. Bull*. **2006**, *132*, 249–268, doi:10.1037/0033-2909.132.2.249.
11. Mager, U.; Nowak, P. Effects of student participation in decision making at school. A systematic review and synthesis of empirical research. *Educ. Res. Rev.* **2012**, *7*, 38–61, doi:10.1016/j.edurev.2011.11.001.
12. Siribunnam, S.; Nuangchalerm, P.; Jansawang, N. Socio-scientific decision making in the science classroom. *Int. J. Cross-Discipl. Subj. Educ.* **2014**, *5*, 1777–1782.
13. Lee, Y.C.; Grace, M. Students' reasoning processes in making decisions about an authentic, local socio-scientific issue: Bat conservation. *J. Biol. Educ.* **2010**, *44*, 156–165, doi:10.1080/00219266.2010.9656216.
14. Saunders, K.J.; Rennie, L.J. A Pedagogical Model for Ethical Inquiry into Socioscientific Issues In Science. *Res. Sci. Educ.* **2013**, *43*, 253–274, doi:10.1007/s11165-011-9248-z.
15. Sadler, T.D. Informal reasoning regarding socioscientific issues: A critical review of research. *J. Res. Sci. Teach.* **2004**, *41*, 513–536, doi:10.1002/tea.20009.
16. Sadler, T.D., Ed. *Socio-Scientific Issues in the Classroom: Teaching, Learning and Research*; Springer: Dordrecht, The Netherlands, 2011.
17. Zeidler, D.L.; Walker, K.A.; Ackett, W.A.; Simmons, M.L. Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Sci. Educ.* **2002**, *86*, 343–367, doi:10.1002/sce.10025.
18. Sadler, T.D.; Romine, W.L.; Topçu, M.S. Learning science content through socio-scientific issues-based instruction: A multi-level assessment study. *Int. J. Sci. Educ.* **2016**, *38*, 1622–1635, doi:10.1080/09500693.2016.1204481.

[9] The style of reference used within Chapter 4.7 is according to the journal's guidelines.

19. Kolsto, S.D. ‘To trust or not to trust,…’-pupils’ ways of judging information encountered in a socio-scientific issue. *Int. J. Sci. Educ.* **2001**, *23*, 877–901, doi:10.1080/09500690117217.
20. Zeidler, D.L.; Lewis, J. Unifying themes in moral reasoning on socioscientific issues and discourse. In *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education*; Zeidler, D.L., Ed.; Kluwer Academic Publishers: Dordrecht, Netherlands, 2003, pp. 289–306.
21. Dawson, V.; Venville, G. Introducing High School Biology Students to Argumentation About Socioscientific Issues. *Can. J. Sci. Math. Technol. Educ*. **2013**, *13*, 356–372, doi:10.1080/14926156.2013.845322.
22. Driver, R.; Newton, P.; Osborne, J. Establishing the norms of scientific argumentation in classrooms. *Sci. Educ*. **2000**, *84*, 287–312, doi:10.1002/(SICI)1098-237X(200005)84:3<287:AID-SCE1>3.3.CO;2-1.
23. Sadler, T.D.; Barab, S.A.; Scott, B. What Do Students Gain by Engaging in Socioscientific Inquiry? *Res. Sci. Educ*. **2007**, *37*, 371–391, doi:10.1007/s11165-006-9030-9.
24. Ratcliffe, M.; Grace, M. *Science Education for Citizenship: Teaching Socio-Scientific Issues*; Open University Press: Maidenhead, UK, 2003.
25. Levy Nahum, T.; Ben-Chaim, D.; Azaiza, I.; Herskovitz, O.; Zoller, U. Does STES-Oriented Science Education Promote 10th-Grade Students’ Decision-Making Capability? *Int. J. Sci. Educ.* **2009**, *32*, 1315–1336, doi:10.1080/09500690903042533.
26. Ardoin, N.M.; DiGiano, M.L.; O’Connor, K.; Podkul, T.E. The development of trust in residential environmental education programs. Environ. *Educ. Res*. **2017**, *23*, 1335–1355, doi:10.1080/13504622.2016.1144176.
27. Sadler, T.D. Situated learning in science education: Socio-scientific issues as contexts for practice. *Stud. Sci. Educ*. **2009**, *45*, 1–42, doi:10.1080/03057260802681839.
28. Cebrián, G.; Junyent, M. Competencies in Education for Sustainable Development: Exploring the Student Teachers’ Views. *Sustainability* **2015**, *7*, 2768–2786, doi:10.3390/su7032768.
29. Bond, D.P.; Grasby, S.E. On the causes of mass extinctions. *Palaeogeogr. Palaeocl*. **2017**, *478*, 3–29, doi:10.1016/j.palaeo.2016.11.005.
30. Brose, U.; Blanchard, J.; Eklöf, A.; Galiana, N.; Hartvig, M.; Hirt, M.; Kalinkat, G.; Nordström, M.C.; O’Gorman, E.J.; Rall, B.C.; et al. Predicting the consequences of species loss using size-structured biodiversity approaches. *Biol. Rev.* **2017**, *92*, 684–697.
31. Doran, P.; Zimmerman, K. Examining the Scientific Consensus on Climate Change. *Eos* **2009**, *90*, 22–23.
32. Munday, P.L. New perspectives in ocean acidification research: Editor’s introduction to the special feature on ocean acidification. *Biol. Lett*. **2017**, *13*, 1–3, doi:10.1098/rsbl.2017.0438.
33. Mathis, J.; Cooley, S.; Yates, K.; Williamson, P. Introduction to this Special Issue on Ocean Acidification: The Pathway from Science to Policy. *Oceanography* **2015**, *25*, 10–15, doi:10.5670/oceanog.2015.26.
34. Wood, H.E.; Marlin, N.; Mudway, I.S.; Bremner, S.A.; Cross, L.; Dundas, I.; Grieve, A.; Grigg, J.; Jamaludin, J.B.; Kelly, F.J.; et al. Effects of Air Pollution and the Introduction of the London Low Emission Zone on the Prevalence of Respiratory and

Allergic Symptoms in Schoolchildren in East London: A Sequential Cross-Sectional Study. *PLoS ONE* **2015**, *10*, e0109121, doi:10.1371/journal.pone.0109121.

35. Swami, A.; Chauhan, D. Impact of air pollution induced by automobile exhaust pollution on air pollution tolerance index (APTI) on few species of plants. *Int. J. Sci. Res.* **2015**, *4*, 342–343.
36. Dionisio, K.L.; Frame, A.M.; Goldsmith, M.-R.; Wambaugh, J.F.; Liddell, A.; Cathey, T.; Smith, D.; Vail, J.; Ernstoff, A.S.; Fantke, P.; et al. Exploring consumer exposure pathways and patterns of use for chemicals in the environment. *Toxicol. Rep.* **2015**, *2*, 228–237, doi:10.1016/j.toxrep.2014.12.009.
37. Little, A.W.; Green, A. Successful globalisation, education and sustainable development. *Int. J. Educ. Dev*. **2009**, *29*, 166–174, doi:10.1016/j.ijedudev.2008.09.011.
38. Sartori, S.; Da Silva, F.L.; De Souza Campos, Lucila Maria. Sustainability and sustainable development: A taxonomy in the field of literature. *Ambient. Soc*. **2014**, *17*, 1–22.
39. Leal Filho, W. Dealing with misconceptions on the concept of sustainability. Int. J. *Sustain. High. Ed*. **2000**, *1*, 9–19, doi:10.1108/1467630010307066.
40. Hawkes, J. *The Forth Pillar of Sustainability: Culture's Essential Role in Public Planning*; Common Ground Publishing: Melbourne, Australia, 2001.
41. Yencken, D.; Wilkinson, D. *Resetting the Compass: Australia's Journey towards Sustainability*; CSIRO Publishing: Collingwood, Australia, 2000.
42. Vare, P.; Scott, W. Learning for a Change: Exploring the relationship between education and sustainable development. *J. Educ. Sustain. Dev*. **2007**, *1*, 191–198, doi:10.1177/097340820700100209.
43. United Nations Educational, Scientific and Cultural Organization. *Education for Sustainable Development Goals: Learning Objectives*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2017.
44. Collier, G. Reflections on sustainability: Questioning the knowing and the doing. *Geogr. Educ.* **2004**, *17*, 19–25.
45. Boeve-de Pauw, J.; Gericke, N.; Olsson, D.; Berglund, T. The Effectiveness of Education for Sustainable Development. *Sustainability* **2015**, *7*, 15693–15717, doi:10.3390/su71115693.
46. Andersson, K.; Jagers, S.; Lindskog, A.; Martinsson, J. Learning for the Future? Effects of Education for Sustainable Development (ESD) on Teacher Education Students. *Sustainability* **2013**, *5*, 5135–5152, doi:10.3390/su5125135.
47. Boehmer-Christiansen, S. The geo-politics of sustainable development: Bureaucracies and politicians in search of the holy grail. *Geoforum* **2002**, *33*, 351–365.
48. Dale, A.; Newman, L. Sustainable development, education and literacy. *Int. J. Sustain. High. Ed.* **2005**, *6*, 351–362, doi:10.1108/14676370510623847.
49. Laurie, R.; Nonoyama-Tarumi, Y.; McKeown, R.; Hopkins, C. Contributions of education for sustainable development (ESD) to quality education: A synthesis of research. *J. Educ. Sustain. Dev*. **2016**, *10*, 226–242.
50. McKeown, R.; Hopkins, C. Moving Beyond the EE and ESD Disciplinary Debate in Formal Education. *J. Educ. Sustain. Dev*. **2016**, *1*, 17–26, doi:10.1177/097340820700100107.

51. Summers, M.; Childs, A.; Corney, G. Education for sustainable development in initial teacher training: Issues for interdisciplinary collaboration. *Environ. Educ. Res.* **2005**, *11*, 623–647, doi:10.1080/13504620500169841.
52. Sleeter, C.E.; Flores Carmona, J. *Un-Standarizing Curriculum: Multicultural Teaching in the Standards-Based Classroom*, 2nd ed.; Teachers College Press: New York, NY, USA, 2017.
53. Pittman, K.J.; Irby, M.; Yohalem, N.; Wilson-Ahlstrom, A. Blurring the lines for learning: The role of out-of-school programs as complements to formal learning. *New Dir. Youth Dev.* **2004**, *2004*, 19–41, doi:10.1002/yd.71.
54. Noddings, N. *Education and Democracy in the 21st Century*; Teachers' College Press: New York, NY, USA, 2012.
55. Brundiers, K.; Wiek, A.; Redman, C.L. Real-world learning opportunities in sustainability: From classroom into the real world. *Int. J. Sustain. High. Ed*. **2010**, *11*, 308–324, doi:10.1108/14676371011077540.
56. Rowe, D. Education for a sustainable future. *Science* **2007**, *317*, 323–324.
57. Ha-Brookshire, J.; Norum, P. Cotton and sustainability: Impacting student learning through sustainable cotton summit. *Int. J. Sustain. High. Ed.* **2011**, *12*, 369–380, doi:10.1108/14676371111168287.
58. Winter, J.; Cotton, D. Making the hidden curriculum visible: Sustainability literacy in higher education. *Environ. Educ. Res.* **2012**, *18*, 783–796, doi:10.1080/13504622.2012.670207.
59. Lipscombe, B.P.; Burek, C.V.; Potter, J.A.; Ribchester, C.; Degg, M.R. An overview of extra-curricular education for sustainable development (ESD) interventions in UK universities. *Int. J. Sustain. High. Ed.* **2008**, *9*, 222–234, doi:10.1108/14676370810885853.
60. National Foundation for Educational Research. Active Citizenship and Young People: Opportunities, Experiences and Challenges in and Beyond School: Research Report No 732, 2006. Available online: https://files.eric.ed.gov/fulltext/ED502417.pdf (accessed on 24.10.2018).
61. Veugelers, W. Creating critical-democratic citizenship education: Empowering humanity and democracy in Dutch education. *J. Comp. Int. Educ*. **2007**, *37*, 105–119, doi:10.1080/03057920601061893.
62. Mahoney, J.L.; Cairns, R.B. Do extracurricular activities protect against early school dropout? *Dev. Psychol.* **1997**, *33*, 241–253, doi:10.1037/0012-1649.33.2.241.
63. Feldman, A.F.; Matjasko, J.L. The role of school-based extracurricular activities in adolescent development: A comprehensive review and future directions. *Rev. Educ. Res.* **2005**, *75*, 159–210.
64. Ecarius, J.; Klieme, E.; Stecher, L.; Woods, J. *Extended Education: An International Perspective: Proceedings of the International Conference on Extracurricular and Out-of-School Time Educational Research*; Barbara Budrich Publisher: Opladen, Germany, 2013.
65. Stecher, L. *Extended Education as Part of the German General Education System: Status quo, Developments, and Policy Issues: Paper Presented at the 3rd Meeting of NEO ER*; Sungkyunkwan University: Seoul, South Korea, 2014.
66. Lewis, J.; Leach, J. Discussion of Socio-scientific Issues: The role of science knowledge. *Int. J. Sci. Educ*. **2006**, *28*, 1267–1287, doi:10.1080/09500690500439348.

67. *Dawson, V.; Carson, K. Using climate change scenarios to assess high school students' argumentation skills. *Res. Sci. Technol. Educ.* **2016**, *35*, 1–16, doi:10.1080/02635143.2016.1174932.
68. Higgins, J.P.T.; Green, S. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0; 2011. Available online: www.handbook.cochrane.org (accessed on 24.10.2018).
69. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D. Reprint-preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Phys. Ther*. **2009**, *89*, 873–880.
70. Moher, D.; Shamseer, L.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst. Rev*. **2015**, *4*, 1, doi:10.1186/2046-4053-4-1.
71. Korpershoek, H.; Harms, T.; Boer, H. de; van Kuijk, M.; Doolaard, S. A Meta-Analysis of the Effects of Classroom Management Strategies and Classroom Management Programs on Students' Academic, Behavioral, Emotional, and Motivational Outcomes. *Rev. Educ. Res.* **2016**, *86*, 643–680, doi:10.3102/0034654315626799.
72. Naish, M. Decisions, decisions! Teaching and assessing environmental thinking. *Geogr. Educ.* **1986**, *5*, 31–34.
73. Randle, D. Ecocabins: Monitoring our impact. *Green Teach.* **1994**, *38*, 33–35.
74. Law, M.; Stewart, D.; Letts, L.; Pollock, N.; Bouch, J.; Westmorland, M. Critical Review Form—Quantitative Review Form; 2007. Available online: https://www.unisa.edu.au/Global/Health/Sansom/Documents/iCAHE/CATs/McMasters_Quantitative%20review.pdf (accessed on 24.10.2018).
75. Letts, L.; Wilkins, S.; Law, M.; Stewart, D.; Bosch, J.; Westmorland, M. Guidelines for Critical Review form: Qualitative Studies; 2007. Available online: http://www.unisa.edu.au/PageFiles/23703/7B%20McMasters_qualreview_version2%200%5B1%5D.pdf (accessed on 24.10.2018).
76. Glaze, A.L.; Goldston, M.J. U.S. Science Teaching and Learning of Evolution: A Critical Review of the Literature 2000-2014. *Sci. Educ.* **2015**, *99*, 500–518, doi:10.1002/sce.21158.
77. van der Zanden, P.J.; Denessen, E.; Cillessen, A.H.; Meijer, P.C. Domains and predictors of first-year student success: A systematic review. *Educ. Res. Rev*. **2018**, *23*, 57–77, doi:10.1016/j.edurev.2018.01.001.
78. Heath, P.A.; Hawk, R. Deciding about energy. *Sci. Child.* **1983**, *20*, 86–88.
79. Rönnebeck; Silke; Bernholt; Sascha; Ropohl; Jan, M. Searching for a common ground - a literature review of empirical research on scientific inquiry activities. *Stud. Sci. Educ.* **2016**, *52*, 161–197.
80. *Gresch, H.; Bögeholz, S. Identifying Non-Sustainable Courses of Action: A Prerequisite for Decision-Making in Education for Sustainable Development. *Res. Sci. Educ.* **2013**, *43*, 733–754, doi:10.1007/s11165-012-9287-0.
81. *Gresch, H.; Hasselhorn, M.; Bögeholz, S. Training in Decision-making Strategies: An approach to enhance students' competence to deal with socio-scientific issues. *Int. J. Sci. Educ*. **2013**, *35*, 2587–2607, doi:10.1080/09500693.2011.617789.
82. *Belova, N.; Eilks, I.; Feierabend, T. The evaluation of role-playing in the context of teaching climate change. *Int. J. Sci. Math. Educ.* **2015**, *13*, 165–190.

83. *Eggert, S.; Nitsch, A.; Boone, W.J.; Nückles, M.; Bögeholz, S. Supporting Students’ Learning and Socioscientific Reasoning About Climate Change—The Effect of Computer-Based Concept Mapping Scaffolds. *Res. Sci. Educ.* **2017**, *47*, 137–159, doi:10.1007/s11165-015-9493-7.
84. *Gresch, H.; Hasselhorn, M.; Bögeholz, S. Enhancing Decision-Making in STSE Education by Inducing Reflection and Self-Regulated Learning. *Res. Sci. Educ.* **2017**, *47*, 95–118, doi:10.1007/s11165-015-9491-9.
85. *Mannion, G. Borderland voices and practices: The ambiguity of children’s participation in school ground greening. *Can. J. Environ. Educ.* **2005**, *10*, 1–15.
86. *Grace, M. Developing High Quality Decision-Making Discussions About Biological Conservation in a Normal Classroom Setting. *Int. J. Sci. Educ.* **2009**, *31*, 551–570, doi:10.1080/09500690701744595.
87. *Nicolaou, C.T.; Korfiatis, K.; Evagorou, M.; Constantinou, C. Development of decision-making skills and environmental concern through computer-based, scaffolded learning activities. *Environ. Educ. Res.* **2009**, *15*, 39–54, doi:10.1080/13504620802567007.
88. *Paraskeva-Hadjichambi, D.; Hadjichambis, A.C.; Korfiatis, K. How students’ values are intertwined with decisions in a socio-scientific issue. *Int. J. Environ. Sci. Educ.* **2015**, *10*, 493–513.
89. *Dori, Y.J.; Tal, R.T. Formal and informal collaboration projects: Engaging in industry with environmental awareness. *Sci. Educ.* **2000**, *84*, 95–113.
90. *Jager, H.d.; van der Loo, F. Decisionmaking in Environmental Education: Notes from Research in the Dutch NME-VO Project. *J. Environ. Educ.* **1990**, *22*, 33–42.
91. *Cincera, J.; Kovacikova, S. Being an EcoTeam Member: Movers and Fighters. *Appl. Environ. Educ. Com.* **2014**, *13*, 227–233, doi:10.1080/1533015X.2015.972299.
92. *Jiménez-Aleixandre, M.-P. Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *Int. J. Sci. Educ.* **2002**, *24*, 1171–1190, doi:10.1080/09500690210134857.
93. *Siegel, M.A. High school students’ decision making about sustainability. *Environ. Educ. Res.* **2006**, *12*, 201–215, doi:10.1080/13504620600689003.
94. *Levine Rose, S.; Calabrese Barton, A. Should great lakes city build a new power plant? How youth navigate socioscientific issues. *J. Res. Sci. Teach.* **2012**, *49*, 541–567, doi:10.1002/tea.21017.
95. *Emery, K.; Harlow, D.; Whitmer, A.; Gaines, S. Compelling evidence: An influence on middle school students’ accounts that may impact decision-making about socioscientific issues. *Environ. Educ. Res.* **2017**, *23*, 1115–1129, doi:10.1080/13504622.2016.1225673.
96. *Roth, W.-M.; Lee, S. Science education as/for participation in the community. *Sci. Educ.* **2004**, *88*, 263–291, doi:10.1002/sce.10113.
97. *Kim, M.; Tan, H.T. A Collaborative Problem-solving Process through Environmental Field Studies. *Int. J. Sci. Educ.* **2013**, *35*, 357–387, doi:10.1080/09500693.2012.752116.
98. Eggert, S.; Bögeholz, S. Students’ use of decision-making strategies with regard to socioscientific issues: An application of the Rasch partial credit model. *Sci. Educ.* **2010**, *94*, 230–258, doi:10.1002/sce.20358.
99. Schneider, J.; Hutt, E. Making the grade: A history of the A–F marking scheme. *J. Curric. Stud.* **2014**, *46*, 201–224, doi:10.1080/00220272.2013.790480.

100. Köller, O.; Trautwein, U.; Lüdtke, O.; Baumert, J. Zum Zusammenspiel von schulischer Leistung, Selbstkonzept und Interesse in der gymnasialen Oberstufe [The interaction of acadamic achievment, self-concept and interest in high school]. *Z. Padagog. Psychol.* **2006**, *20*, 27–39, doi:10.1024/1010-0652.20.12.27.
101. Steffen, B.; Hößle, C. "Dafür bin ich nicht ausgebildet, dafür bin ich nicht fortgebildet." Diagnose von Bewertungskompetenz durch Biologielehrkräfte als "Negiertes Bewältigen" ["I cannot do this, I am not educated in this" biology teachers' diagnosis of decision-making as "negated coping"]. In *Befähigung zu gesellschaftlicher Teilhabe [Empowerment to civic participation]*; Menthe, J., Höttecke, D., Zabka, T., Hammann, M., Rothgangel, M., Eds.; Waxmann: Münster, Gernamy; New York, NY, USA, 2016; pp. 95–106.
102. Aikenhead, G.S. Collective decision making in the social context of science. *Sci. Educ.* **1985**, *69*, 453–475.
103. Reischert, K.; Hößle, C. Wie Schüler ethisch bewerten. Eine qualitative Untersuchung zur Strukturierung und Ausdifferenzierung von Bewertungskompetenz in bioethischen Sachverhalten bei Schülern der Sek. I.: [How students judge ethically. A qualitative study on the structure and differentiation of competence of moral judgement with respect to bioethical issues concerning students of Sek. I]. *Zeitschrift für Didaktik der Naturwissenschaften* **2007**, *13*, 125–143.
104. Zeidler, D.L.; Sadler, T.D. Social and Ethical Issues in Science Education: A Prelude to Action. *Sci. Educ*. **2008**, *17*, 799–803, doi:10.1007/s11191-007-9130-6.
105. Grace, M.M.; Ratcliffe, M. The science and values that young people draw upon to make decisions about biological conservation issues. *Int. J. Sci. Educ.* **2002**, *24*, 1157–1169, doi:10.1080/09500690210134848.
106. Acar, O.; Turkmen, L.; Roychoudhury, A. Student Difficulties in Socio-scientific Argumentation and Decision-making Research Findings: Crossing the borders of two research lines. *Int. J. Sci. Educ*. **2009**, *32*, 1191–1206, doi:10.1080/09500690902991805.
107. Elliott, J. A. *Introduction to Sustainable Development*; Routledge: London, UK, 2012.
108. Evans, R.T.; Kilinc, E. History of place-based education in the school studies field. *Adiyaman Univ. J. Soc. Sci.* **2013**, *11*, 2233–2237.
109. Dewey, J. *The School and Society,* 2nd ed.; University of Chicago Press: Chicago, IL, USA, 1915.
110. Brkich, K.L. Urban fifth graders' connections-making between formal earth science content and their lived experiences. *Cult. Stud. Sci. Educ*. **2014**, *9*, 141–164.
111. Gruenewald, D.A.; Koppelman, N.; Elam, A. Our place in history: Inspiring place-based social history in schools and communities. *J. Mus. Educ*. **2007**, *32*, 231–240.
112. Gruenewald, D.A.; Smith, G.A. Making room for the local. In *Place-Based Education in the Global Age: Local Diversity*; Gruenewald, D.A., Smith, G.A., Eds.; Lawrence Erlbaum Associates: New York, NY, USA, 2007; pp. xiii–xxiii.
113. Holfelder, A.-K. *Orientierungen von Jugendlichen zu Nachhaltigkeitsthemen [Young peoples' orientation in topics related to sustainable development. The educational meaning of implicit knowledge in the context of EDS]*; Springer Fachmedien Wiesbaden: Wiesbaden, Germany, 2018.
114. Akin, S.; Calik, B.; Engin-Demir, C. Students as Change Agents in the Community: Developing Active Citizenship at Schools. *Educ. Sci. Theor. Pract*. **2017**, *17*, doi:10.12738/estp.2017.3.0176.

115. Chawla, L.; Cushing, D.F. Education for strategic environmental behavior. *Environ. Educ. Res.* **2007**, *13*, 437–452, doi:10.1080/13504620701581539.
116. Wals, A.E. Mirroring, Gestaltswitching and transformative social learning. *Int. J. Sustain. High. Ed.* **2010**, *11*, 380–390, doi:10.1108/14676371011077595.
117. Tilbury, D.; Wortman, D. *Engaging People in Sustainability*; IUNC: Grand, UK, 2004.
118. Robson, C. *Real World Research*, 3rd ed.; Wiley: Chichester, UK, 2011.
119. James, A.; Prout, A. *Constructing and Reconstructing Childhood*; Falmer: Basingstoke, UK, 1990.
120. Bae, S.H. Values and Prospects of Extended Education: A Critical Review of the Third NEO ER Meeting. *Int. J. Res. Ext. Educ*. **2014**, *2*, 135–141.
121. Pocock, S.J.; Collier, T.J.; Dandreo, K.J.; Stavola, B.L. de; Goldman, M.B.; Kalish, L.A.; Kasten, L.E.; McCormack, V.A. Issues in the reporting of epidemiological studies: A survey of recent practice. *BMJ* **2004**, *329*, 883–888, doi:10.1136/bmj.38250.571088.55.
122. Seow, P.-S.; Pan, G. A Literature Review of the Impact of Extracurricular Activities Participation on Students' Academic Performance. *J. Educ. Bus*. **2014**, *89*, 361–366, doi:10.1080/08832323.2014.912195.
123. Zeidler, D.L. Socioscientific issues as a curriculum emphasis. In *Handbook of Research on Science Education Volume II*; Lederman, N.G., Abell, S.K., Eds.; Routledge: London, UK, 2014; pp. 697–726.
124. Owens, D.C.; Sadler, T.D.; Zeidler, D.L. Controversial issues in the science classroom. *Phi Delta Kappan* **2017**, *99*, 45–49, doi:10.1177/0031721717745544.
125. Reitschert, K.; Hößle, C. Ethisches Bewerten im Biologieunterricht [Ethical decision-making in the biology classroom]. In *Fachmethodik: Biologie-Methodik: Handbuch für die Sekundarstufe I und II: [Methods for biology education: A guideline for Sek I and Sek II]*; Spörhase, U., Ruppert, W., Eds.; Cornelson: Berlin, Germany, 2010; pp. 227–230.
126. Ratcliffe, M. Pupil decision-making about socio-scientific issues within the science curriculum. *Int. J. Sci. Educ.* **1997**, *19*, 167–182.
127. Bourn, D. Teachers as agents of social change. *Int. J. Dev. Educ. Glob. Learn*. **2016**, *7*, 63–77, doi:10.18546/IJDEGL.07.3.05.
128. Mezirow, J. Transformative Learning: Theory to Practice. *New Dir. Adult Contin. Educ.* **1997**, *1997*, 5–12, doi:10.1002/ace.7401.
129. Wals, A.E.; Jickling, B. "Sustainability" in higher education. *Int. J. Sustain. High. Ed.* **2002**, *3*, 221–232, doi:10.1108/14676370210434688.

4.8. Appendix

Table 4.2: A summary of the qualified literature.

Study	#	Purpose	Selected Outcomes
Jager, H. de, & van der Loo, F. (1990)	[90]	The study evaluates two learning units with regards to their effect on students' decision-making.	Students' willingness to use energy more carefully declines if energy conservation would cost money or reduce comfort.
Dori, Y., J., & Tal, R., T. (2000)	[89]	The study explores the effect of a collaborative learning project on students' environmental attitude and knowledge as well as their decision-making skills.	Environmental knowledge and attitude as well as higher-order thinking skills improved significantly over the course of the learning project ($p<0.0001$).
Jimenez-Aleixandre, M. (2002)	[92]	The study explores the aspects of knowledge and skills required to address a SSI and to make informed decisions about it.	By comparing the warrants used by students and used by the expert, a rich overlap in its content is displayed. Therefore, students are seen as active knowledge producers.
Roth, W., & Lee, S. (2004)	[96]	The study purposes to redefine scientific literacy in favour for a social component.	Scientific literacy is characterized through social rather than individual activities. Science education has to be seen 'as' and 'for' participation in the community.
Mannion, G. (2005)	[85]	This study designs a typology of practice categorizing children's participation in school ground developments.	Derivation of five types of participation practice: The Outdoor Classroom Practices of a Safe Childhood Practices of the Tribal Child Practices of Community Practices of Citizenship and Sustainability.
Siegel, M. A. (2006)	[93]	The study examines the effect of a computer program on students' decision-making and reasoning in a sustainability-related context.	The group using the computer program has better posttest scores (partially) than the control group regarding the use of evidence when making decisions.

Grace, M. (2009)	[86]	The study explores the effectiveness of a group discussion approach on students' decision-making in a sustainability-related context.	A comparison of pre- and posttest comments reveals a general shift to higher-level responses subsequent to the discussions.
Nicolaou, C. T., Korfiatis, K., Evagorou, M., & Constantinou C. (2009)	[87]	The study examines students' development of decision-making and environmental concern with aid of computer-based and scaffolded learning activities.	Students' decision-making improved through the learning activity ($p<.001$) with a larger gain in score among the high performing group.
Levine Rose, S., & Barton, A. C. (2012)	[94]	The study aims to understand how students frame their decision about SSIs such as building a power plant.	Findings support the use of frames as conceptual tools and shed light on the importance of personal experiences when making decisions.
Gresch, H., & Bögeholz, S. (2013).	[80]	Through the implementation of a computer-based intervention, this study investigates the effect of decision-making strategies on decision-making in the context of sustainability.	Using knock-out criteria when making a decision was found to be more comfortable for students than performing a full trade-off.
Gresch, H., Hasselhorn, M., & Bögeholz, S. (2013)	[81]	The study examines the effects of decision-making strategies on students' decision-making in sustainability-related contexts.	The treatment group of this study was significantly better than the control group in describing the presented decision-making strategies ($p<0.001$).
Kim, M., & Tan, H. (2013)	[97]	This study explores possibilities for interdisciplinary problem-solving processes among secondary school children using environmental challenges.	The relevance and certainty of information as well as the development of respectful relationships were taken as important criteria for students' joint decision-making.
Cincera, J., & Kovacikova, S. (2014)	[91]	The study investigates how members of EcoSchools reflect on the program and its influence.	Schools that implement the program with a sense of autonomy and a change orientation satisfy and activate their members. Contrarily, a limited freedom to choose and a restricted involvement lead to negative emotions among the members.

Belova, M. Eilks, I., & Feierabend, T. (2015)	[82]	The study explores the effect of role-plays that are set in the context of climate change on students' decision-making.	Most of the students' arguments originate in everyday life experiences. The inaccurate use of science-related arguments further lead to an incorrect use of scientific language.
Paraskeva-Hadjichambi, D. Hadjichanmbis, A., & Korfiatis, K. (2015)	[88]	The study aims to explore how students' decisions are interlinked with their personal values.	SSIs' social dimension was an important factor for students' decision-making.
Dawson, V., & Carson, K. (2017)	[67]	The study explores the effectiveness of SSI-scenarios to assess students' decision-making and argumentation skills.	The developed scenarios are suitable to assess the quality of students' argumentation skills.
Eggert, S., Nitsch, A., Boone W., Nückles, M., & Bögeholz, S. (2017)	[83]	The study investigates concept mapping as a learning strategy in order to promote students' decision making in the context of sustainability.	Equipping students with relevant concepts is highly beneficial for their conceptual knowledge. Enabling students free mapping conditions is highly beneficial for their argumentation.
Emery, K., Harlow, D., Whitmer, A., & Gaines, S. (2017)	[95]	The study aim at understanding the role of data and evidence in students' decision making about SSIs.	Prior knowledge was a major factor for students' decisions. When using further information, students not inevitably link scientific contributions with strong evidence.
Gresch, H., Hasselhorn, M., & Bögeholz, S. (2017)	[84]	This study examines the effect of decision-making strategies, combined with reflections on others' decision-making processes, on students' decision-making in the context of sustainability. Moreover, the elements of self-regulated learning are from interest.	Self-regulated learning has a positive effect on students' decision-making.

5. STUDY 2

Fostering students' socioscientific decision-making: Exploring the effectiveness of an environmental science competition[10]

To make informed decisions has been acknowledged as an essential ability to negotiate socioscientific issues. However, many young people show an inadequate understanding of how to make well-informed decisions, particularly in contexts that are connected to environmental problems. This paper aims to explore the effectiveness of an environmental science competition (BundesUmweltWettbewerb, BUW) to foster students' socioscientific decision-making. Two different instruments, a paper-pencil test (N = 196 students) and retrospective interviews (N = 10 students), have been used in two successive studies. In addition, both of the applied instruments are investigated theoretically using the "assessment triangle" of the National Research Council (2001) as a framework. The results of our studies indicate that participating in the environmental science competition predominantly fosters students' socioscientific decision-making in its pre-selectional phase. We further argue that promoting the selectional phase of decision-making requires explicit and instructional guidance. With respect to the assessment of socioscientific decision-making, a focus on either structural (decision-making strategies) or contextual (decision content) conditions is argued. Outcomes are discussed in terms of theoretical and practical implications

Keywords: Socioscientific decision-making, environmental science competition, assessment of instruments, socioscientific issues

[10] This is the peer-reviewed version of the following article: Garrecht, C., Eckhardt, M., Höffler, T. N., & Harms, U. (2020). Fostering students' socioscientific decision-making: Exploring the effectiveness of an environmental science competition. *Disciplinary and Interdisciplinary Science Education Research*, *2*(5), 1-16. The final print version of this article is available at: https://doi.org/10.1186/s43031-020-00022-7.

5.1. Introduction

Ongoing developments in science and technology increasingly shape social issues that "require scientific knowledge for informed decisionmaking" (Zeidler & Nichols, 2009, p. 49). These controversial issues at the intersection of science and society, such as genetic engineering and nuclear power, have been called socioscientific issues (SSI) within the science education community (Fleming, 1986; Sadler, 2004). To negotiate these issues, students must reach beyond the mere comprehension of scientific content by embedding their science understanding within a social and political context (Kinslow, Sadler & Nguyen, 2019; Kolstø, 2001; Romine, Sadler & Kinslow, 2017). As a result of this embeddedness, SSI serve as a suitable tool to contextualize students' science learning within real-world contexts (Zeidler, 2014). The inclusion of SSI into the classroom presents both new challenges and opportunities for science education. On a practical level, traditional classroom practices are often teacher-focused and content-specific. This dependency might challenge the implementation of debatable and interdisciplinary SSI (Sadler, 2009). Extracurricular learning opportunities, on the contrary, might offer a pathway beyond the traditional framing of classroom practices to address previously neglected societal considerations (Bell, Lewenstein, Shouse & Feder, 2009). On a more conceptual level, "well-structured decision-making processes are essential" (Gresch, Hasselhorn & Bögeholz, 2013, p.2587) to negotiate SSI. Yet, many young people show an inadequate understanding of how to make well-informed decisions, particularly in contexts that are connected to environmental issues (Collins et al., 2007; McBeth & Volk, 2009). This article merges both considerations and investigates the effectiveness of an extracurricular science competition with an environmental focus to support students' socioscientific decision-making. Two different instruments, a paper-pencil test by Eggert and Bögeholz (2010) and retrospective interviews (inspired by Paul, Lederman & Groß, 2016), have been implemented in two successive studies. In addition, both of the applied instruments are evaluated in the light of the "assessment triangle" (National Research Council, 2001) to provide some assessment-related notes. The "assessment triangle", established by several US-based education scholars, has been used repeatedly in science education research to frame the development and evaluation of assessment instruments (e.g., Opfer, Nehm & Ha, 2012).

5.2. Theoretical background

5.2.1. Socioscientific decision-making

Drawing upon the insights from cognitive psychology, the existence of dual-process models has been widely acknowledged (for a review, see Gerrard, Gibbons, Houlihan, Stock & Pomery, 2008). These models contain two different systems of thinking: a subliminal (so-called 'system 1') and a deliberate one ('system 2'). When operating in system 1, intuitive and parallel processing of information takes place. Decisions that are made within this first system are predominantly unconscious, automatic, and quick (Glöckner & Betsch, 2008). Conversely, when operating in system 2, people engage in rational thinking. Coming to a conclusion within this system entails the deliberate, analytical, and sequential processing of the given information (Betsch, 2008). It is this second system that initiates informed decision-making on complex problems (Wilson & Keil, 2001).

Complex problems that can be found at the interface between science and society have been labeled as socioscientific issues (SSI) within the science education community (Fleming, 1986; Sadler, 2004). SSI describe socially debated problems with process-related and/or conceptual associations to science (Sadler, 2011). These issues are inherently open-ended; in other words, they are without straightforward solutions (Kolstø, 2001). The respective debate is, conclusively, characterized by diverse perspectives and multiple decision-making options (Sadler, Barab & Scott, 2007). The social embeddedness of SSI additionally provides a framework to contextualize students' science-informed decisions in a meaningful way (Kinslow et al., 2019). As a result, students' decision-making in SSI has been of particular interest to many scholars in science education (e.g., Grace, 2009; Levy Nahum, Ben-Chaim, Azaiza, Herskovitz & Zoller, 2009; Sadler, 2011; Siribunnam, Nuangchalerm & Jansawang, 2014).

Decision-making in SSI (socioscientific decision-making) concerns students' ability to reflect upon multiple perspectives while bearing in mind relevant scientific data as well as societal and personal values (Lee & Grace, 2010). In a literature review by Fang, Hsu, and Lin (2019), several models of socioscientific decision-making were analyzed. Resulting from this comparison, Fang et al. (2019) established an overarching framework for socioscientific decision-making that consists of three interconnected phases. Phase 1 includes the recognition and construction of a specific decision-making space. Within this phase, information is analyzed and reasoned to explore possible solution approaches. Since these activities prepare a final decision, this phase is also called the pre-selectional phase (Betsch & Haberstroh, 2005). Phase 2 deals with the selection of a suitable decision-making strategy to assess and decide upon the different solution approaches (e.g., compensatory and non-compensatory strategy). In the following, this second phase is referred to as the selectional phase (Betsch & Haberstroh, 2005). Phase 3 summarizes the conscious reflection of phases 1 to 3 as well as the acting upon the respective decision.

Drawing upon this theoretical framework, socioscientific decision-making is considered as a multi-phased process. An exemplary model for socioscientific decision-making that considers all three phases is the "Göttinger competence model for socioscientific decision-making" by Eggert and Bögeholz (2006). This model comprises four competence dimensions addressing students' understanding and reflecting of values and norms, the development of possible solutions and their assessment (Bögeholz, Böhm, Eggert & Barkmann, 2014). The first two competence dimensions (*understanding and reflecting values and norms* and *developing and reflecting solutions*) belong to the pre-selectional phase (Bögeholz, 2007). The actual making of a decision (*evaluating and reflecting solutions qualitatively*) is associated with the selectional phase (ibid, 2007). Within this latter phase, the assessment of different options is central. Here, students are commonly confronted with various solution approaches (Gresch et al., 2013). In order to make an informed decision, students are required to engage in different decision-making strategies. A highly intuitive procedure characterizes a low level of decision-making (Eggert & Bögeholz, 2006). Conversely, more elaborate decision-making is presented when students engage in a systematic evaluation of all given information (ibid, 2006). In many cases, this is described by students' full trade-off of information, meaning that all provided information is assessed regarding its advantageous and disadvantageous features (Jungermann, Pfister & Fischer, 2005). In addition to this rather rational and individual-based understanding of socioscientific decision-making, a systematic literature review by Garrecht, Bruckermann, and Harms (2018) emphasizes a more social perspective on decision-making. Here, socioscientific decision-making is also perceived as students' empowerment to cooperate in the decision-making process by sharing their thoughts and opinions. Both perceptions, the individual-based and the collaborative one, seem essential in the context of SSI. On the one hand, students are required to tackle these issues independently (e.g., daily consumer decisions). On the other hand, they need to debate local and global issues collectively on a more public level (Sipos, Battisti & Grimm, 2008).

5.2.2. The assessment of socioscientific decision-making

Diverse methods from both the qualitative and quantitative research spectrum have been used to assess students' socioscientific decision-making. Reitschert and Hößle (2007), for example, conducted interviews with secondary school students to examine the structure of socioscientific decision-making in the context of preimplantation diagnostics. One of their interests concerned students' ability to recognize the moral relevance of a decision situation. Using the method of qualitative content analysis, Reitschert and Hößle were able to divide students' socioscientific decision-making into several quality levels. These levels ranged from a descriptive-pragmatic perception of the problem (level 1) to the (emotionally charged) recognition of the ethical problem (level 2), to the objective recognition of the moral-ethical value-dilemma (level 3). According to Reitschert and Hößle (2007), this kind of assessment can be helpful for teachers to support a transparent and constructive discussion about SSI. Others in the field of science education have used audio and video recordings during group work (e.g., Böttcher & Meisert, 2013) and role-play (e.g., Agell, Soria & Carrió, 2015) to explore socioscientific decision-making. Besides these qualitative approaches, decision-making has also been examined using quantitative methods. Paraskeva-Hadjichambi, Hadjichambis, and Korfiatis (2015), for example, used paper-pencil tests to assess younger students' use of decision-making strategies and their weighting of criteria. One of their main results drove the establishment of three decision-making types: strong anthropocentric, weak anthropocentric, and ecocentric decision-makers. This differentiation not only highlights the subliminal influence of values during the decision-making process but also illustrates how using strategies can help to reflect upon them. As summarized in Fang et al. (2019), most of these assessment endeavors intend to either investigate informal and evidence-based reasoning (pre-selectional phase) or students’ use of decision-making strategies (selectional-phase).

5.2.3. The assessment of instruments used to measure socioscientific decision-making

In order to reflect upon the quality of instruments used to measure decision-making, this study employs a framework by the National Research Council (2001). The so-called “assessment triangle” identifies three critical aspects for evaluation: cognition, observation, and interpretation. The first component, *cognition*, contains the understanding that a “construct should be defined by a cognitive model of learning that articulates how students develop understanding and progress in the sophistication of their thinking in the domain” (Ketterlin-Geller, Perry & Adams, 2019, p.63). This component describes students’ achievements that are intended for assessment. The second component, *observation*, entails the operationalization of this cognitive model. The operationalization results in a product (e.g., an instrument) that collects data through students’ responses or behavior. The third component, *interpretation*, explores the question as to what extent the observed data match the previously developed cognitive model. Drawing upon these theoretical considerations, the “assessment triangle” can serve as an overarching framework to structure a systematic evaluation of existing instruments (cf. Marion & Pellegrino, 2007). For this paper, it will serve as a rubric to examine both instruments used to assess socioscientific decision-making.

5.2.4. The socioscientific context of sustainable development

On a global scale, human activity has already contributed to an increase of the average temperature by about 0.8-1.0°C above pre-industrial levels (Hansen, Ruedy, Sato & Lo, 2010; IPCC, 2018). Resulting from this rapid increase in temperature, extreme weather events such as heatwaves, drought, and heavy rain, as well as their social, economic, and ecological consequences will be a severe risk for life on Earth (IPCC, 2018). In order to stem a further increase, the discussion about how to decrease our carbon footprint and how to live more sustainably needs to be promoted. Participating in these discussions, however, challenges students with complex decision situations that are both factually and ethically complex (Jickling, 1992).

As a consequence, students need to be supported in their ability to make informed and sustainable decisions (Gresch & Bögeholz, 2013). Yet, traditional classroom practices might be of limited use due to disciplinary boundaries and formal requirements such as temporal limits and assessment standards (McKeown & Hopkins, 2016; Sleeter & Flores Carmona, 2017). The less formal and often interdisciplinary nature of extracurricular activities, in contrast, can represent a sound alternative to address students’ decision-making in sustainability-related issues (Garrecht et al., 2018). We thus chose an extracurricular learning environment with sustainability-related focus for the context of this study: an environmental science competition.

5.2.5. The learning environment: An environmental science competition

The BundesUmweltWettbewerb (BUW) is a project-oriented science competition that invites students (individually or in small groups, aged between 10 and 20) to elaborate on sustainability-related questions. In order to participate in the BUW, two main requirements (R1, R2) have to be fulfilled. First, students have to choose a sustainability-related issue that can be encountered within their local environment. They are then asked to investigate the issue's underlying socioscientific processes. During this step, students engage in the elaboration of scientific as well as ethical considerations that are connected to their issue. Subsequent to these theoretical deliberations, participants are asked to generate and implement practical solution approaches (R1). Secondly, participants have to write a project report that summarizes the development and results of their project. Concrete guiding questions, provided in the BUW-guidelines, lead students' writing. The questions also encourage them to monitor, reflect and discuss their project critically (R2; see Figure 5.1).

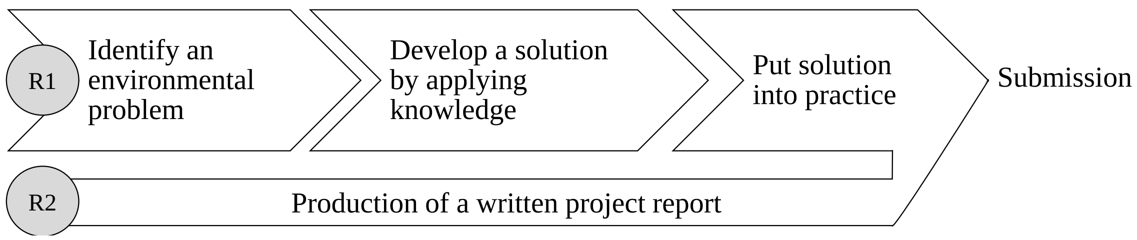

Figure 5.1: Steps of participation in the BUW with two main requirements (R1: investigation of SSI and development of solution approach(es), R2: completion of project report).

The BUW constitutes an extracurricular learning opportunity that implements an inquiry-based learning approach. This approach is exemplified by various self-regulated learning elements throughout students' participation, such as setting project goals, monitoring and evaluating the project development, and approaching scientific problems in an explorative manner. This autonomy in learning can require participants to make sensible decisions (Pedaste et al., 2015; Stefanou, Perencevich, DiCintio & Turner, 2004). Furthermore, the thematic orientation of the competition requires students to elaborate on complex SSI, which have been acknowledged for their potential to engage students in decision-making about contemporary matters (Grace, 2009; Levy Nahum et al., 2009; Sadler, 2011; Siribunnam et al., 2014).

Based on the competition's inherent structure and the features mentioned above, we claim that the BUW constitutes a suitable opportunity for the development of participants' socioscientific decision-making. As presented in Table 5.1, we could identify opportunities for practical expressions of socioscientific decision-making based on cognitive and affective norms.

Table 5.1: Exemplary aspects of the BUW potentially initiating socioscientific decision-making.

Extracts from the BUW-guideline	**Practical implementations**	**Connection to the development of decision-making**
"On a personal level, what does this issue mean to you?" (p.14)	Reflect upon individual and societal values and norms	Values and norms (on a personal as well as on a societal level) are implicitly embedded in SSI. They need to be considered when making an informed decision (e.g., Eggert & Bögeholz, 2006).
"What has been done so far to solve the issue?" (p.14) The BUW encourages "to develop solutions based on theoretical considerations and to put them into practice" (p.4)	Available information needs to be assessed, possible courses of action need to be evaluated	Decisions in the context of sustainability-related issues are complex and involve the assessment of various information from different stakeholders (e.g., Sartori, Da Silva & Capos, 2014).
"If you decided between different courses of action, reason your choice of action" (p.15)	Decide between equally conceivable courses of action	SSI are complex and ill-structured. Corresponding decision situations display a set of possible options that need to be decided upon (e.g., Arvai et al., 2004; Jungermann et al., 2005; Siegel, 2006).
"The task [of this competition] is to examine a local environmental issue and to research the cause and its connections" (p.4)	Choose a local, environmental issue	Global SSI, which cannot be experienced within the local environment, might be too abstract for students. However, once the issue is locally interconnected "the problems become immanent and complicated with personal, economic, political and social factors" (Jho, Yoon & Kim, 2014, p.1147). This place-based notion can help students to connect and engage with the SSI on a personal level (Herman, Zeidler & Newton, 2018; Zeidler, Herman & Sadler, 2019).
You can take part "individually or in teams" (p.5)	Different perspectives, opinions, and solution approaches need to be discussed when working collaboratively	The ability to acknowledge different perspectives is a vital element of informed decision-making and reasoning in SSI (e.g., Kahn & Zeidler, 2019).
"You should generate a theoretical and practical overview, […], do experiments […] and transfer knowledge into action" (p.4)	Inquiry-based and self-regulated learning environment	Inquiry-based learning activities can require students to make sensible decisions (Pedaste et al., 2015). The perceived autonomy in self-regulated learning environments encourages decision-making (Stefanou et al., 2004).

Prior research in the field of science education predominantly focused on classroom interventions. These interventions were often designed to foster socioscientific decision-making in a particular context (e.g., energy usage). This study, in contrast, explores the potentials of an extracurricular intervention to promote socioscientific decision-making in local, self-chosen contexts. This place-based notion might be specifically valuable for their engagement with SSI (Herman et al., 2018).

5.2.6. Research aim

Although decision-making has been presented as an essential ability to negotiate SSI, many young people show an inadequate understanding of how to make well-informed decisions. This particularly refers to socioscientific contexts that are related to environmental issues (Collins et al., 2007; McBeth & Volk, 2009). From this, a twofold research approach is evolving. First, interventions that aim to develop students' socioscientific decision-making need to be assessed in their effectiveness. Secondly, this presupposes the implementation of suitable instruments to evaluate students' socioscientific decision-making.

The aim of this article is to assess an intervention (BUW) in its effectiveness to promote students' socioscientific decision-making in two successive studies (Study 1 and Study 2)[11]. In addition to this, the applied instruments of each study will be evaluated in light of the "assessment triangle" (National Research Council, 2001).

5.3. Study 1

Study 1 aims to measure participants' socioscientific decision-making *before* and *after* the competition. The applied instrument builds upon an existing model for socioscientific decision-making (Eggert & Bögeholz, 2006; see 5.2.1). Within this study, we distinctly focused on the model's competence dimension: *evaluating and reflecting solutions qualitatively* (Eggert & Bögeholz, 2010). Since this competence dimension is affiliated with the selectional phase, decision-making defines "the ability to systematically evaluate possible courses of action and […] to systematically make a final decision" (Gresch & Bögeholz, 2013, p.734). The center of attention is, therefore, participants' ability to apply appropriate decision-making strategies (selectional phase).

5.3.1. Methods

Study 1 implemented a quasi-experimental pretest-posttest with control-group design to measure a possible development in decision-making due to participation in the BUW.

5.3.1.1. Sample

As our study involved human participants, ethical approval was obtained from the competent Ministries for Education. Participation in the study was voluntary. All

[11] **Important note**: Within Chapter 5, the words 'Study 1' and 'Study 2' refer to what has been called 'sub-study 1' and 'sub-study 2' within this dissertation. Due to the publication policies, a change in the wording (from Study 1 to sub-study 1 and from Study 2 to sub-study 2) was not made.

participants and parents were provided with information about the survey beforehand. Parents had to sign an informed consent form for their children to participate.

Overall, N = 196 students (55% female) aged between 13 and 20 (M = 15.65, SD = 1.67) completed a questionnaire before (pretest, October/November 2017) and after (posttest, March/April 2018) participation in the BUW. To authentically match the competition's distribution of participants, our sample was drawn from four federal states (Southern, Northern, and Eastern Germany). Furthermore, students attended three different school types (grammar school, comprehensive school, and pre-vocational school). From N = 196 students, n = 81 students (73% female) were participants of the BUW 2017/2018 and hence belonged to our treatment group. The remaining n = 115 students (47% female) served as a control group.

5.3.1.2. Collection of data

Participants of the treatment and the control group were given a 45-minute paper-and-pencil questionnaire on decision-making by Eggert and Bögeholz (2010). This questionnaire consists of four open-ended tasks in the context of sustainable development (see Table 5.2). The first two tasks investigate students' ability to evaluate different options to tackle a real-world and sustainability-related issue. Students are required to decide upon the most sustainable option and to explain their decision-making approach. Since all the given options are perceived as equally conceivable, elaborate decision-making is assumed when students evaluate each option in terms of its advantages and its disadvantages (Jungermann et al., 2005). The third task evaluates students' ability to reflect upon the decision-making of fictional students. In the fourth task, students are asked to advice on how to advance these fictional decision-making approaches. According to the analysis by Eggert and Bögeholz (2010), this questionnaire can be used to adequately describe students' decision-making in the selectional phase.

Table 5.2: Description of the instrument's tasks.

Task No.	Context	Task	Format of answer
Task 1	Stabilization of codfish population in the Baltic Sea	Evaluate the given options (four options) and choose the most suitable one	Open-ended, written answer
Task 2	Containment of invasive plants	Evaluate the given options (four options) and choose the most suitable one	Open-ended, written answer
Task 3	Consumer decision on chocolate	Reflect upon fictional students' decision-making	Multiple choice
Task 4	Consumer decision on chocolate	Advice on how to advance decision-making	Open-ended, written answer

This questionnaire was administered in a pretest-posttest design (before and after the competition) to all students of the treatment and the control group. While students of the treatment group took part in the intervention (BUW), students of the control group did not take part in any intervention between the pre- and posttest.

5.3.1.3. Analysis of data

Students' answers (tasks 1- 4) were analyzed using the respective scoring guide (Eggert & Bögeholz, 2010). Concerning the first two tasks, students' decision-making processes were central to the analysis. Therefore, students' written answers were scored regarding three aspects: 1) the amount of chosen and rejected option(s), 2) students' use of positive and/or negative aspects to argue for or against the option(s) and 3) whether students explicitly weighted criteria. As stated in Eggert and Bögeholz (2010), elaborate decision-making is understood as students' full trade-off of information. Following this understanding, the maximum score was assigned when students were able to discuss all four options with at least one negative and one positive aspect per option. The latter tasks (reflection upon other students' decision-making and ideas for improvement) scored students' ability to recognize the strategy that was used by fictional students. Scores were also assigned for students' suggestions on how to advance their decision-making (e.g., consider positive *and* negative aspects of an option). Exemplary items, as well as more detailed information on how to score students' answers, are provided in Eggert and Bögeholz (2010) and Gresch et al. (2013). For the analysis of reliability, Cronbach's α was calculated. For the first two tasks of the questionnaire (decision-making strategies), the internal consistency was acceptable with Cronbach's α for task one = .71 (pretest) and .66 (posttest) and for task two = .70 (pretest) and .63 (posttest). For task three and four (reflection), the internal consistency was inacceptable with Cronbach's α = .35 (pretest) and = .34 (posttest). Similar results reporting only moderate reliabilities within this second section have also been found in other studies (e.g., Gresch et al., 2013). Accordingly, data from task three and four were not used in further analysis. A second person coded about 25% of all questionnaires. The interrater reliability was found to be sufficient (Cohen's Kappa: ≥ .76). Items that were scored differently by the two independent raters were re-examined. In addition to the scoring proposed by Eggert and Bögeholz (2010), the number of arguments used to describe the advantages and disadvantages of each option in task one and task two was recorded in a separate file.

5.3.2. Results

In the pretest, participants of the BUW (treatment group) did not differ significantly from the control group in their decision-making (t (195) = 3.186, p = .989). Table 5.3 presents the descriptive statistics from the questionnaire's administration at two times (pretest and posttest). For each scenario, students' average performance (according to the scoring guide by Eggert and Bögeholz, 2010), as well as the number of arguments, are provided.

Table 5.3: Descriptive statistics of Study 1.

Time	Scenario	Decision-making				Number of Arguments			
		Mean		**SD**		**Mean**		**SD**	
		TG	CG	TG	CG	TG	CG	TG	CG
Pretest	Codfish	.58	.55	.48	.42	3.2	4.0	3.0	3.6
	Invasive plants	.60	.63	.46	.40	4.7	5.2	3.7	3.9
Posttest	Codfish	.58	.57	.41	.42	4.3	3.6	3.5	2.9
	Invasive plants	.61	.60	.40	.36	5.3	4.7	3.9	3.5

Note: TG for students of the treatment group and CG for students of the control group

With regard to the development of participants' decision-making, there were no significant changes from the pretest to the posttest in either group (for all $F < 1$). This was valid for the separate calculation of each scenario (codfish and invasive plant) as well as for the combination of both scenarios and their scores. Conclusively, participants of the BUW did not enhance their decision-making significantly over the course of the competition.

With reference to students' use of arguments, there was no significant difference between the treatment and the control group in the pretest (t (195) = 1.68, p = .355). Combining the pretest data with the posttest data, a statistically significant interaction between time and group was found. This was valid for the calculation of each scenario (codfish: F (1, 195) = 12.05, p = .001, η^2_{part}: .058; invasive plants: F (1, 194) = 5.98, p = .015, η^2_{part}: .03) as well as for their combined calculation (F (1, 194) = 183.38, p = .001, η^2_{part}: .056).

5.3.3. Discussion of results

The purpose of Study 1 was to examine the competition's effect on participants' decision-making using a questionnaire by Eggert and Bögeholz (2010). This questionnaire analyzes decision-making in its selectional phase and, therefore, focuses on students' ability to use appropriate decision-making strategies. Our data show no significant effects on students' decision-making due to participation in the BUW. This result contrasts with previous studies that applied the same questionnaire before and after interventions (e.g., Eggert, Ostermeyer, Hasselhorn & Bögeholz, 2013; Gresch et al., 2013; 2017).

One explanation could be that the questionnaire was commonly implemented before and after short term interventions. These interventions might have been more precise in their learning aims and outcomes (e.g., Gresch et al., 2017). Besides, previous studies that used this questionnaire predominantly focused on the promotion of students' decision-making strategies (e.g., Gresch et al., 2013). The BUW, in contrast, can be regarded as a long term intervention that does not seek to develop participants' use of strategies explicitly. Thus it is assumed that the poor study results are mainly due to the lack of instructional guidance on how to strategically make a decision (here: full trade-off).

5.3.3.1. Number of used arguments

As reported in 5.3.2, participants of the treatment group did not improve in their ability to use an appropriate decision-making strategy (here: full trade-off; evaluating *each* option mentioning *at least* one advantage and one disadvantage). However, they still showed an increased use of arguments after the competition and compared to the control group. This result suggests that participants of the treatment group did not refer to the whole set of options (at least one advantage and one disadvantage per option; maximum score in the test instrument); instead, they investigated fewer option(s) more in-depth (more than one advantage and/or disadvantage per option; consistent score in the test instrument but more arguments in total). Participants' collaborative work during the competition might explain this development towards a more thorough discussion during the competition. A study by Evagorou and Osborne (2013) investigated students' collaborative argumentation in SSI. Similar to our results, they found that some groups were able to provide more arguments than others. In their discussion, the authors interpreted this increase in arguments as students' ability to present more solutions and, in turn, their ability to present a more successful final product. Simon and Amos (2011) similarly assume that "by engaging collaboratively in argumentation activities that make reasoning public, students can gain collective experience of constructing arguments, justifying arguments with evidence, evaluating alternative arguments, and reflecting on the outcomes of argumentation" (p.170). Therefore, we assume that the BUW encourages participants to engage with selected options comprehensively, rather than comparing all the available options on a superficial level. This thorough engagement, in turn, is connected to aspects such as reasoning, which is further associated with the pre-selectional phase of decision-making (Betsch & Haberstroh, 2005).

5.3.4. Discussion of the instrument

To guide the following considerations, we use the three components of the "assessment triangle" (National Research Council, 2001) as a structuring rubric (see 5.2.3).

Cognition: Eggert and Bögeholz's instrument builds upon the "Göttinger competence model for socioscientific decision-making" (Eggert & Bögeholz, 2006) and its competence dimension *evaluating and reflecting solutions qualitatively*. This competence dimension postulates different competence levels from naïve to elaborate decision-making. Elaborate decision-making describes students' ability to engage in adequate decision-making strategies. In the context of sustainable development, the most suitable strategy often displays students' full trade-off. A full trade-off includes evaluating all of the given information concerning its advantageous as well as its disadvantageous features (Jungermann et al., 2005). The importance of trade-offs for informed decision-making has been outlined by several other scholars in the field of science education and psychology (e.g., Arvai et al., 2004; Jungermann et al., 2005; Siegel, 2006). Yet, with a sole focus on students' ability to perform a full trade-off, the actual decision context appears to be subordinate. We critically wonder if students might fall into an automatic process of solely recalling all the given information to obtain the maximum score in the test instrument. This automatism could further lead to a neglect of their personal linkage to the specific decision context.

Observation: To process task 1 and task 2 of the questionnaire, students are required to report on their decision-making approach. Following the cognitive principles described above, the instrument generates higher scores when students perform a full trade-off. This illustrates a proper operationalization of the underlying theoretical model. To enable students to perform a full trade-off, all necessary information is given in the respective tasks. This availability of information initially offers each participant the same conditions and assures a certain degree of comparability between students' decision-making approaches (Coe, 2010). Yet, the translation of information into cognitive processes might be more or less successful for specific subgroups of students, e.g., dependent on their reading level (Lane & Iwatani, 2016). In addition to the comparability, the availability of diverse information encourages students to frame a decision problem from different angles, highlighting economic as well as environmental and social aspects (Arvai et al., 2004). On the flip side, the provision of well-prepared information and a particular decision problem means that students do not need to identify an issue of relevance for themselves. To identify an issue of relevance, however, is an essential aspect of the decision-making process (Lewis & Leach, 2006). Furthermore, most of the decision situations we face in our day-to-day life lack a considerable amount of information (Burke, 1990). This, in turn, raises the question if it would be equally important to teach students negotiating SSI even though a certain amount of information is missing or uncertain.

Interpretation: This instrument features a strict and clearly structured analysis scheme that secured a reliable scoring. Following the theoretical underpinnings, the item score precisely reflects whether or not students are able to use the preferred decision-making strategy. Nevertheless, students' decision-making performances are evaluated based on a manufactured product (their written answers). It seems debatable to assume that this product is a comparable replica of the actual decision-making process (Blömeke, Gustafsson & Shavelson, 2015). In addition, the analysis scheme assigns scores whenever students explicitly weight criteria in their written answers. On the one hand, this seems reasonable since students should be encouraged to connect SSI with their own values (Oulton, Dillon & Grace, 2004). Yet, in most cases, the weighting of criteria happens implicitly (Uskola, Maguregi & Jiménez-Aleixandre, 2010). We therefore expect that some students failed to gain this score since they considered their values indirectly.

5.4. Study 2

The second study aimed to supplement the insights from Study 1 by expanding the investigated set of decision-making dimensions. In addition to Eggert and Bögeholz's competence dimension *evaluating and reflecting solutions qualitatively* (Study 1), this study also examines their first and second competence dimension (*understanding and* *reflecting values and norms* and *developing and reflecting solutions*) as well as the previously introduced cooperative perspective on decision-making (cf. Garrecht et al., 2018).

5.4.1. Method

Based on the results gained in Study 1, Study 2 follows a mixed-methods explanatory design (Creswell, 2014). This includes the conduction of an additional, qualitative data collection to explain the previous, quantitative insights (Study 1). In contrast to Study 1, Study 2 is located in an interpretivist paradigm. This paradigm seeks to provide researchers with a deeper understanding of the investigated phenomena from the participants' point of view (Thanh & Thanh, 2015). Informed by these considerations, we decided to implement retrospective interviews to explore participants' experiences with decision-making *during* the competition.

5.4.1.1. Sample

In the second study, 10 BUW-participants (80% female) from two different project groups were part of our data collection. About half of the participants (n = 6) came from Southern Germany, the other group (n = 4) lived in Northern Germany.

5.4.1.2. Collection of data

The development of a suitable instrument was based on Paul, Lederman, and Groß's "retrospective query on learning processes" (2016, p. 2371). Similar to the sample of our study, Paul et al. (2016) also gathered data from participants of a project-oriented science competition. The method of retrospective inquiry allowed interviewees of their study to connect their conceptions about experimentation with their individual competition project. Based on Paul et al.'s (2016) promising insights, this study likewise engaged in a retrospective inquiry. In total, we developed 26 problem-oriented interview questions that intended to investigate participants' experiences with decision-making during the competition. Interviews lasted about 30 minutes and were conducted individually.

5.4.1.3. Analysis of data

The interviews were recorded using a voice recorder. After their transcription, data were processed using MAXQDA 2018. For the purpose of analysis, we used the method of content analysis according to Mayring (2014) and Kuckartz (2012). Concerning the development of categories, we opted for a hybrid form using a deductive as well as an inductive approach. In a first analysis step, relevant information was deductively drawn from the existing literature to explore participants' decision-making. The selected literature referred to the previously introduced "Göttinger competence model for socioscientific decision-making" (Eggert & Bögeholz, 2006) and Garrecht et al.'s (2018) remarks about the more cooperative notion of decision-making. The respective passages of the literature were extracted, structured, and summarized in several main categories. In a second, inductive analysis step, the main categories were applied to the interview transcripts. Each paragraph of the transcripts was reviewed and used to create finer divisions between the main categories. In other words, this second step aimed to review and differentiate the previously developed main categories into sub-categories that emerged from the interview data. In a last step, the interview transcripts were reviewed once again and relevant passages were assigned to the established categories (coding). A second and independent rater analyzed about 25% of all interviews (*n* = 3) for reliability. The interrater reliability was found to be good (Cohen's Kappa: ≥ .84).

5.4.2. Results

The result section features two overarching interests: (1) Participants' decision-making according to Eggert and Bögeholz (2006) and (2) participants' decision-making in reference to Garrecht et al. (2018).

5.4.2.1. Participants' decision-making according to Eggert and Bögeholz (2006)

In a first, deductive analysis step, we established three main categories that align with Eggert and Bögeholz's (2006) competence dimensions (Göttinger competence model for socioscientific decision-making). The first two competence dimensions *understanding and reflecting values and norms* (main category 1) and *developing and reflecting solutions* (main category 2) belong to the pre-selectional phase. The third competence dimension *evaluating and reflecting solutions qualitatively* (main category 3) belongs to the selectional phase. In addition to the three main categories, 10 sub-categories emerged from the interview data. The distribution of codes will be described in the following.

Pre-selectional phase: The first competence dimension (*understanding and reflecting values and norms*) encompasses students' ability to "comprehend and reflect on personal and societal values and norms that are inherent to socioscientific issues" (Bögeholz et al., 2014, p.237). Codes ascribed to the first competence dimension (main category 1) were assigned thirty-three times. This main category was further divided into five sub-categories. Three of the sub-categories describe participants' awareness of contemporary and sustainability-related issues: pollution (*n* = 5 codes), the loss of biodiversity (*n* = 9 codes), and scarcity of resources (*n* = 6 codes). The fourth sub-category addresses participants' concern regarding the well-being of humans and other animals (*n* = 7 codes). Codes ascribed to the last sub-category report participants' awareness of an intra- and intergenerational responsibility (*n* = 6 codes).

The second competence dimension (*developing and reflecting solutions*) summarizes students' ability to reflect upon complex information as well as their ability to develop sustainable solutions (Bögeholz et al., 2014). The second competence dimension (main category 2) assimilated ninety-five codes and was further split into five sub-categories. The first two sub-categories summarize participants' dealing with information. The first sub-category describes participants' quest for information and is called 'information research' (*n* = 36 codes). The second sub-category is named 'handling of sources' (*n* = 6 codes) and reports how participants evaluated the origin of information. The third sub-category links to the development and evaluation of solutions and is called ‘scientific working’ (n = 42 codes). Codes were assigned whenever students showed elements of inquiry-based working. The fourth sub-category gathers students’ views regarding the ‘generation of possible solutions’ (n = 9 codes). The last sub-category reports students’ ‘evaluation of possible solutions’ (n = 2 codes) in the light of economic, ecological, and social consequences.

Selectional phase: The third competence dimension (*evaluating and reflecting solutions qualitatively*) describes students’ “ability to systematically evaluate possible courses of action and […] to systematically make a final decision” (Gresch & Bögeholz, 2013, p.734). Codes assigned to this third main category describe the systematic evaluation of options and participants’ consideration of respective advantages and disadvantages (n = 15 codes).

5.4.2.2. Participants’ decision-making in reference to Garrecht et al. (2018)

The second, overarching interest refers to the cooperative perspective on decision-making (cf. Garrecht et al., 2018). In a deductive step, this perspective was outlined as the main category: ‘empowerment’. In a second, inductive step, this main category was split into two sub-categories: ‘agents of change’ and ‘empowerment of scientific interest’. There was no overlap with the codes assigned in 5.4.2.1.

Agents of change: Codes were assigned to the first sub-category whenever participants regarded themselves as agents of change (n = 23 codes). In other words, this sub-category describes participants’ positive experiences when sharing their knowledge and encouraging others to act more sustainably.

Empowerment of scientific interest: In this second sub-category, participants perceived empowerment as a self-regulated driving forward of their scientific interests (n = 8 codes).

For an overview, Table 5.4 presents exemplary quotes from the participants for each of the main categories.

Table 5.4: Exemplary quotes of the participants.

Reference	Main category	Exemplary quotes
Eggert & Bögeholz (2006)	Understanding and reflecting values and norms	**Sub-category: intra- and intergenerational responsibility** “It’s quite obvious […] when I’m 80 years old, there won’t be any oil anymore […] and that’s something I don’t want to witness. And that’s why I believe it’s important to start thinking about it now. Because this isn’t something that only my children, grandchildren, and great-grandchildren witness […] but even I am witnessing this and I don’t want to blame myself for this.” [Student 1 – 00:03:44 – 00:04:23]

	Developing and reflecting solutions	**Sub-category: Scientific working** "I think the most exciting part is to plan and conduct an experiment and to analyze it afterwards. To see the difference between the things you actually had planned and what turns out to be the result. Problems often arise while working. We, for example, said that we want to do a pilot study first. And this pilot study showed us that the product wasn't working because the pump wasn't strong enough. And therefore the experimental setup has changed accordingly." [Student 9 – 00:26:21 – 00:27:01]
	Evaluating and reflecting solutions qualitatively	"Actually, it's never the case that there are only equivalent options […] it's more like a different weighting or a hierarchy where we have to say what's more important […] so different aspects are unequally important. And it's of little avail to have the most awesome product when, in the end, it's so expensive that nobody is going to use it." [Student 9 – 00:25:18 – 00:26:12]
Garrecht et al. (2018)	Empowerment	**Sub-category: Agents of change** "I do believe that my attitude towards sustainable development has changed because I realized during the project work that one can actually do something using simple methods […] and many people like the idea and this shows how excited they are that young adults support the environment and care for a sustainable development" [Student 7, 00:14:44-00:15:20]
	Empowerment	**Sub-category: Empowerment of scientific interest** "I think the greatest difference is that we thought of a research question on our own, that we planned the experiments on our own and that we don't have a strict procedure to follow. If you think about a placement, for example in chemistry, [...] having a note that says what we need and what we have to do and so on. And this is, of course, different [in the competition context] because we don't have somebody who thinks for us" [Student 8 – 00:33:43 – 00:34:27]

5.4.3. Discussion of results

5.4.3.1. Participants' decision-making according to Eggert and Bögeholz (2006)

Pre-selectional phase: Concerning the first competence dimension (*understanding and reflecting values and norms*), a majority of participants demonstrated awareness of three contemporary hazards: (1) the loss of biodiversity, (2) pollution, and (3) scarcity of resources. This awareness can mostly be explained by the thematic orientation of interviewees' BUW-projects. Both groups either addressed the jeopardies connected to marine pollution or the decrease in biodiversity within their projects. Additionally, sustainability-related issues such as the loss of biodiversity have been picked up frequently in students' social media conversations (Andersson & Öhman, 2017). Since young adults demonstrate a lively exchange with social media, these issues might be well-represented topics for them. The ability to identify such relevant issues, as demonstrated by the interviewees, is further understood as a prerequisite for students' engagement in a reasoned discussion and respective decision-making (Lewis & Leach, 2006). About half of the participants explicitly linked these hazards to health consequences for humans and animals. This, the ability to anticipate consequences, appears highly important for the protection of present and later generations and constitutes an essential facet of informed decision-making (Kelly, 2006; Reitschert & Hößle, 2007). Last but not least, half of the interviewees also mentioned an intra- and intergenerational responsibility. This mentioning seems reasonable since our intergenerational responsibility is widely accepted as a cornerstone of sustainable development (Brundtland Commission, 1987).

With regard to all three competence dimensions, the second dimension (*developing and reflecting solutions*) accumulates the highest number of codes (n = 91). Every single interviewee shared experiences that connected to the quest for information or the evaluation of its sources. This information research prepares an informed decision and both aspects are "considered to be an important sub-process of decision making" (Lindow & Betsch, 2019, p.24). The critical assessment of information seems particularly important concerning the propagation of so-called 'fake news' (Lazer et al., 2018), which can lead to decisions that are based on a biased sample and lack essential information (Glöckner & Betsch, 2008). Another aspect that was outlined by the majority of interviewees concerned their inquiry-based working during the competition. Inquiring a problem in a self-regulated manner highlights the active and autonomous notion of learners (Ebert-May, Brewer & Allred, 1997). This autonomy might be especially empowering in the context of decision-making (Stefanou et al., 2004).

Selectional phase: The third competence dimension (*evaluating and reflecting solutions qualitatively*) was already investigated in Study 1. In this previous study, no significant developments in participants' decision-making were detected. Conversely, when using the methodological tool of retrospective interviews, supportive statements were found in 80% of the interviews. This result indicates that participants indeed evaluated different courses of action as part of their competition experience; yet, they were not able to apply these strategies explicitly during the written test in Study 1. This result further underpins the previous consideration that dealing with decision-making strategies is solely an implicit aspect of the BUW. Based on this result, one might wonder whether or not the BUW should offer participants more explicit guidance on how to use decision-making strategies. On the one hand, students' deliberate use of decision-making strategies is acknowledged as an important aspect when processing various information to reach an informed conclusion (e.g., Lindow & Betsch, 2019; Papadouris, 2012). On the other hand, any explicit learning intervention during the BUW would reduce aspects of the self-regulated learning environment, which has been positively accentuated by participants.

Drawing upon the total number of codes, we assume that participants of the BUW engaged in a fair amount of decision-making. Overall, the distribution of codes reveals that participants' decision-making can be predominantly located within the pre-selectional phase. The results furthermore indicate that the selectional phase requires more instructional guidance concerning the appropriate use of decision-making strategies.

5.4.3.2. Participants' decision-making in reference to Garrecht et al. (2018)

Agents of change: During the interviews, every single participant expressed feelings of empowerment. For students, empowerment meant to act more sustainably or to encourage others to do so. This understanding portrays participants as capable mediators and accountable social actors in the context of sustainable development (James & Prout, 1990). This interpretation goes in line with results found in a study by Herman et al. (2018), showing that place-based learning opportunities can increase students' expression of care. Similar to the participants of Herman et al.'s study, participants of the BUW also engaged in a place-based SSI. This local connectedness of their project might have encouraged their personal engagement with the SSI during and after the competition. As a result, participants might have felt empowered to share their experiences in this respect. Furthermore, the dynamic interaction between participants and other students potentially inspires a culture of shared decision-making, which can bring forward joint actions for sustainable development (Celino & Concilio, 2011).

Empowerment of scientific interest: The second sub-category describes participants' empowerment in the context of their learning. Most participants considered the competition's self-regulated learning environment as positive and enriching. The self-regulated learning environment was exemplified by, for example, choosing their own project idea, structuring scientific experiments, and general project management. To organize one's learning processes can encourage students to become autonomous learners (Kopzhassarova, Akbayeva, Eskazinova, Belgibayeva & Tazhikeyeva, 2016). Supporting autonomy and ownership, in turn, can motive students to engage with the context of sustainable development (Madsen, Nordin, & Simovska, 2016) and decision-making (Stefanou et al., 2004).

5.4.3.3. Development of decision-making

Retrospective questioning aims to compare students' understanding at two different moments in time. Analyzing the collected data showed no concrete evidence which indicated a development in students' understanding of socioscientific decision-making. One explanation could be that making decisions is an everyday task since our early years. A basic understanding of how to weigh information, for example to reach a decision, is already found in young children (Kachergis, Rhodes & Gureckis, 2017). As a consequence, the procedure of making a decision might be hard to retrieve as a deliberate concept. This lack of awareness might be further strengthened by the implicit nature of everyday decision-making (Haidt, 2007). A second explanation targets the use of decision-making strategies. Many researchers propose the use of decision-making strategies for the elaboration of SSI (Eggert & Bögeholz, 2010; Seethaler & Linn, 2004; Siegel, 2006). However, applying appropriate strategies seems difficult for students, even when they are confronted with a decision situation at that very moment (Hong & Chang, 2004). To assess the use of strategies through *retrospective* methods seems debatable since strategies are not like experiences that can be recalled.

Based on these considerations, applying a method of retrospective inquiry to investigate the *development* of socioscientific decision-making processes might not have been the most suitable approach in this particular context. In light of an interpretivist paradigm, this study allowed broader insights into participants' experiences with decision-making *during* the competition.

5.4.4. Discussion of the instrument

We want to clarify that the results of Study 2 heavily depend on the underlying theoretical constructs, research questions, and interview structure. Study-dependent results do not give direct feedback about the quality of the research tool in general.

Cognition: Retrospective questioning aims to compare students' understanding at two different moments in time. Hence, the underlying cognitive model of the research interest must be distinguishable in separate and observable characteristics. Examining concepts about scientific processes such as experimentation, for example, seems to be highly suitable for this method (Paul & Groß, 2017). In contrast, other research foci might be less appropriate (e.g., socioscientific decision-making).

Observation: The central interest in retrospective research is participants' self-reporting of past experiences (Cox & Hassard, 2007). From an economic perspective, collecting information retrospectively, rather than having several measurement points, is much quicker (Beckett, Da Vanzo, Sastry, Panis & Peterson, 2001). However, the accuracy of recalled processes might be imprecise (ibid). Some interviewees might have trouble remembering the necessary experiences to outline the process and offer adapted "post hoc rationalizations" (Basturkmen, Loewen & Ellis, 2004, p.251) instead. As claimed in 5.4.3.3, changes in decision-making might not even be noticed and, therefore, not processed or stored in the memory (Sudman, Bradburn & Schwarz, 1996). Depending on the particular study context, such as sustainable development within this study, the effects of social desirability must also be considered (Cerri, Thøgersen & Testa, 2019). Nevertheless, the retrospective inquiry "allows the student to reflect on all phases of a learning task" (Chamot & Kupper, 1989, p.252) and hence offers a unique insight into their learning history.

Interpretation: The interviewee constitutes the central interest when using retrospective interviews. This participant-centered data collection can initiate a shift in power between the researcher and the participant (Aléx & Hammarström, 2010). This shift enables participants to elucidate their individual understandings, which enabled us to detect both understandings of decision-making (the systematic and the more cooperative one). Yet, these kinds of qualitative data are exposed to the risk of subjective interpretation and a rigorous data analysis might thus be hampered (Anderson, 2010).

5.5. Conclusion

This study aimed to assess the BUW in its effectiveness to promote students' socioscientific decision-making. In addition, both of the applied instruments were evaluated in light of the "assessment triangle" (National Research Council, 2001).

5.5.1. Effects of the BUW on participants' socioscientific decision-making

With respect to Study 1 and participants' decision-making *before* and *after* the BUW, no significant developments were recorded. Study 2 explored participants' experiences with decision-making *during* the competition. The results suggest a distinct predominance of experiences that can be ascribed to the pre-selectional phase of decision-making.

Drawing upon the theoretical division by Fang et al. (2019), this paper considered socioscientific decision-making as a multi-phased process. Regarding the selectional phase, the results of our studies suggest that enhancing students' decision-making requires explicit instructional guidance on how to apply decision-making strategies. Since the BUW does not offer such explicit learning opportunities, it seems reasonable that participants of the competition did not improve in the respective decision-making phase. Although the qualitative data of Study 2 revealed evidence that participants of the competition had to choose between different courses of action, they were not able to explicitly apply these strategies during the written test in Study 1. Concerning the pre-selectional phase, the results of Study 1 demonstrated significant (yet weak) improvements in participants' number of used arguments. This increase might indicate participants' enhanced ability to elaborate on SSI more in-depth by proposing a higher number of solutions. This interpretation was strengthened by qualitative evidence from Study 2, which revealed students' profound knowledge about their project. Based on the insights from Study 2, we also assume that the self-regulated and inquiry-based aspects of the competition positively affect decision-making in its pre-selectional phase. Last but not least, both notions of decision-making (the individual-based and the more social one) were found to be part of the competition experience.

5.5.2. Measuring socioscientific decision-making

The instrument applied in Study 1 conceptualizes decision-making as students' use of appropriate decision-making strategies. In the context of sustainable development, weighing positive and negative aspects of each option is assumed to be particularly suitable (Eggert & Bögeholz, 2006; Siegel, 2006). This instrument, consequently, considers decision-making on a structural level. The socioscientific context of the task seems rather interchangeable since the use of strategies usually happens on a meta-cognitive level (e.g., Sakschewski, Eggert, Schneider & Bögeholz, 2014; task content: energy-related issue). Study 2 applied retrospective interviews which enabled the exploration of individual as well as social aspects of decision-making. As a consequence, this instrument investigates decision-making on an explorative level. It is, therefore, highly dependent on the research context (e.g., decision-making in a science competition). Overall, we were able to examine socioscientific decision-making on two levels: a structural level (interest in students' application of adequate decision-making strategies, Study 1) and content level (interest in students' reasoning in more contextual terms, Study 2). This differentiation is in line with the results by Fang et al. (2019). For an overview, Table 5.5 summarizes selected characteristics of each instrument as used within the studies.

Table 5.5: Characteristics of the instruments as they have been used within the two studies.

	Study 1	**Study 2**
Reference	Eggert and Bögeholz (2010)	Paul, Ledermann and Groß (2016)
Format of data collection	Paper-pencil-test, open answer format	Interview, semi-structured guideline
Conceptualization of decision-making	Appropriate use of decision-making strategies	According to Eggert and Bögeholz (2010) and Garrecht et al. (2018)
Assessment focus	Structural nature	Explorative nature
Adaptability of context	Yes	No
Decision required?	Yes	No

This subdivision can potentially help future research endeavors to clarify and refine respective aims and outcomes. Last but not least, the implementation of several instruments supported a more holistic perspective on the development of students' decision-making (Kuckartz, 2014). These insights deepened the idea of decision-making as a multi-phased process.

5.5.3. Limitations

A limitation (and a strength) of this study is the intervention's embeddedness in a real-world context. The treatment group displays a highly selective group of strongly motivated students willing to work on a sustainability-related project. Thus, the recruitment of a suitable control group with similar characteristics was not a trivial task. While we could ensure a comparable interest in biology as one highly relevant factor, other variables might have been important as well. However, due to a lack of testing time, this was not possible which might be considered as a possible limitation of our study.

Over the course of the studies, students took part in regular school activities and events connected to their personal development. Concerning the amount of information needed, we assume that it is nearly impossible to control all these variables under the given conditions. As a result, we only have limited explanatory power that results are due to participation in the BUW.

5.5.4. Implications and further research

The results of this paper clarify the potential of inquiry-based learning opportunities with regard to the exploration of SSI. Inquiry-based learning opportunities, such as the BUW, often follow a more progressivist pedagogy and thus provide learning contexts that are more autonomous and student-centered (Lindahl, Folkesson & Zeidler, 2019). As the results of this paper suggest, these learning contexts are particularly suitable to foster students' decision-making in its pre-selectional phase. Another implication targets the teaching practice: Only if teachers are aware of the multi-phased structure and the different aspects of decision-making, they can sensibly evaluate the potentials of their learning opportunity. Vice-versa, teachers can help researchers to understand the practicability of a learning context. This interconnectedness emphasizes the importance of bridging the gap between research and practice, particularly in education.

Based on our research endeavor, several questions remain unanswered. Currently, we assume that inquiry-based elements of the competition contributed to participants' engagement and decision-making. We suggest a separate study to make detailed statements about their effects. This study should be set within similar contextual conditions featuring different treatment groups that partake or do not partake in self-regulated and inquiry-based learning processes. Additionally, a recently published study by Hancock, Friedrichsen, Kinslow, and Sadler (2019) explores teachers' collaborative selection of SSI for an SSI-based framework. Yet, we think it would be at least equally interesting to track students' criteria and choices when it comes to the selection of SSI. This investigation might provide valuable insights into trending contexts of interest amongst adolescents, which could be used by practitioners and researchers alike for instruction design purposes. The BUW requires participants to choose a local SSI as one of the first requirements of participation. It might offer the optimal environment for such a research endeavor.

The wide-ranging consequences of the global increase in temperature will affect the security of individuals and populations worldwide (IPCC, 2018). More than ever, we are in severe need of educational activities that promote novel ideas on how to combat these consequences while equally supporting students in how to make more informed decisions. Concerning this paper's analysis, the BUW appears to be one of these educational activities which can address both the development of sustainability-related ideas and the development of decision-making.

5.6. References

Agell, L., Soria, V., & Carrió, M. (2015). Using role play to debate animal testing. *Journal of Biological Education, 49*(3), 309–321.

Aléx, L. & Hammarström, A. (2008). Shift in power during an interview situation: methodological reflections inspired by Foucault and Bourdieu. *Nursing Inquiry, 15*(2), 169-176.

Anderson, C. (2010). Presenting and evaluating qualitative research. *American Journal of Pharmaceutical Education, 74*(8), 1-7.

Andersson, E. & Öhman, J. (2017). Young people's conversations about environmental and sustainability issues in social media. *Environmental Education Research, 23*(4), 465-485.

Arvai, J. L., Campbell, V. E. A., Baird, A., & Rivers, L. (2004). Teaching students to make better decisions about the environment: Lessons from the decision sciences. *The Journal of Environmental Education, 36*(1), 33–44.

Basturkmen, H., Loewen, S., & Ellis, R. (2004). Teachers' stated beliefs about incidental focus on form and their classroom practices. *Applied Linguistics, 25*(2), 243–272.

Beckett, M., Da Vanzo, J., Sastry, N., Panis, C., & Peterson, C. (2001). The quality of retrospective data: An examination of long-term recall in a developing country. *The Journal of Human Resources, 36*(3), 593–625.

Bell, P., Lewenstein, B. Shouse, A., & Feder, M. (2009). *Learning science in informal environments: People, places and pursuits. National Research Council*. Washington: The National Academies Press.

Betsch, T. (2008). The nature of intuition and its neglect in research on judgment and decision making. In H. Plessner, C. Betsch, & T. Betsch (Eds.), *Intuition in judgement and decision making* (pp. 3–22). New York: Erlbaum.

Betsch, T. & Haberstroh, S. (2005). Current research on routine decision making: Advances and prospects. In T. Betsch & S. Haberstroh (Eds.), *The routines of decision making* (pp. 359–376). Mahwah: Lawrence Erlbaum Associates.

Blömeke, S., Gustafsson, J.-E., & Shavelson, R. J. (2015). Beyond dichotomies. *Zeitschrift für Psychologie, 223*(1), 3–13.

Bögeholz, S. (2007). Bewertungskompetenz für systematisches Entscheiden in komplexen Gestaltungssituationen nachhaltiger Entwicklung [Systematic decision-making in complex situations in sustainable development]. In D. Krüger & H. Vogt (Eds.), *Theorien in der biologiedidaktischen Forschung* (pp. 209–220). Berlin: Springer.

Bögeholz, S., Böhm, M., Eggert, S., & Barkmann, J. (2014). Education for sustainable development in German science education: Past – present – future. *EURASIA Journal of Mathematics, Science & Technology Education, 10*(4), 231–248.

Böttcher, F., & Meisert, A. (2013). Effects of direct and indirect instruction on fostering decision-making competence in socioscientific Issues. *Research in Science Education, 43*(2), 479–506.

Brundtland Commission. (1987). *Our common future*. Oxford: Oxford University Press.

Burke, S. J. (1990). The effects of missing information on decision strategy selection. In M. E. Goldberg, G. Gorn, & R. W. Pollay (Eds.), *Advances in Consumer Research*: *Volume 17* (pp. 250–256). Provo: Association for Consumer Research.

BUW-guidelines (2018). Retrieved from: https://www.buw.uni-kiel.de/wp-content/uploads/2011/02/BUW-Leitfaden_web_1118.pdf

Celino, A. & Concilio, G. (2011). Explorative nature of negotiation in participatory decision making for sustainability. *Group Decision and Negotiation, 20*(2), 255-270.

Cerri, J., Thøgersen, J., & Testa, F. (2019). Social desirability and sustainable food research: A systematic literature review. *Food Quality and Preference, 71*(1), 136–140.

Chamot, A. U. & Kupper, L. (1989). Learning strategies in foreign language instruction. *Foreign Language Annals*, *22*(1), 13–22.

Coe, R. (2010). Understanding comparability of examination standards. *Research Papers in Education*, *25*(3), 271–284.

Collins, S., Swinton, S., Anderson, C. W., Benson, B. J., Brunt, J., Gragson, T., . . . Whitmer, A. C. (2007). *Integrated science for society and the environment: A strategic research initiative*. LTER Network Office.

Cox, J. W. & Hassard, J. (2007). Ties to the past in organization research: A comparative analysis of retrospective methods. *Organization, 14*(4), 475–497.

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches.* Los Angeles: Sage.

Ebert-May, D., Brewer, C., & Allred, S. (1997). Innovation in large lectures: Teaching for active learning. *BioScience, 47*(9), 601–607.

Eggert, S. & Bögeholz, S. (2006). Göttinger Modell der Bewertungskompetenz. Teilkompetenz “Bewerten, Entscheiden und Reflektieren” für Gestaltungsaufgaben Nachhaltiger Entwicklung [Göttingen’s model of decision-making competence - subcompetence “evaluating, deciding and reflecting” in tasks related to sustainable development]. *Zeitschrift für Didaktik der Naturwissenschaften*, *12*(1), 177–199.

Eggert, S. & Bögeholz, S. (2010). Students' use of decision-making strategies with regard to socioscientific issues: An application of the Rasch partial credit model. *Science Education, 94*(2), 230-258.

Eggert, S., Ostermeyer, F., Hasselhorn, M., & Bögeholz, S. (2013). Socioscientific decision making in the science classroom: The effect of embedded metacognitive instructions on students' learning outcomes. *Education Research International, 2013*(3), 1–12.

Evagorou, M. & Osborne, J. (2013). Exploring young students' collaborative argumentation within a socioscientific issue. *Journal of Research in Science Teaching, 50*(2), 209-237.

Fang, S.-C., Hsu, Y.-S., & Lin, S.-S. (2019). Conceptualizing socioscientific decision making from a review of research in science education. *International Journal of Science and Mathematics Education*, *17*(3), 427–448.

Fleming, R. (1986). Adolescent reasoning in socio-scientific issues. *Journal of Research in Science, 23*(8), 677-687.

Garrecht, C., Bruckermann, T., Harms, U. (2018). Students’ decision-making in education for sustainability-related extracurricular activities: A systematic review of empirical studies. *Sustainability, 10*(11), 3876.

Gerrard, M., Gibbons, F. X., Houlihan, A. E., Stock, M. L., & Pomery, E. A. (2008). A dual-process approach to health risk decision making: The prototype willingness model. *Developmental Review, 28*(1), 29–61.

Glöckner, A. & Betsch, T. (2008). Modeling option and strategy choices with connectionist networks: Towards an integrative model of automatic and deliberate decision making. *Judgment and Decision Making, 3*(3), 215–228.

Grace, M. (2009). Developing high quality decision-making discussions about biological conservation in a normal classroom setting. *International Journal of Science Education, 31*(4), 551–570.

Gresch, H., & Bögeholz, S. (2013). Identifying non-sustainable courses of action: A prerequisite for decision-making in education for sustainable development. *Research in Science Education, 43*(2), 733–754.

Gresch, H., Hasselhorn, M., & Bögeholz, S. (2013). Training in decision-making strategies: An approach to enhance students’ competence to deal with socio-scientific issues. *International Journal of Science Education, 35*(15), 2587–2607.

Gresch, H., Hasselhorn, M., & Bögeholz, S. (2017). Enhancing decision-making in STSE education by inducing reflection and self-regulated learning. *Research in Science Education, 47*(1), 95–118.

Haidt, J. (2007). The new synthesis in moral psychology. *Science, 316*(5827), 998–1002.

Hancock, T., Friedrichsen, P., Kinslow, A., & Sadler, T. (2019). Selecting socio-scientific issues for teaching - A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science & Education, 28*(6/7), 639-667.

Hansen, J., Ruedy, R., Sato, M., & Lo, K. (2010). Global surface temperature change. *Reviews of Geophysics, 48*(4), 644.

Herman, B., Zeidler, D., & Newton, M. (2018). Students' emotive reasoning through place-based environmental socioscientific issues. *Research in Science Education*, Online first version retrieved from: https://doi.org/10.1007/s11165-018-9764-1.

Hong, J.-L., & Chang, N.-K. (2004). Analysis of Korean high school students' decision-making processes in solving a problem involving biological knowledge. *Research in Science Education, 34*(1), 97–111.

IPCC [Intergovernmental Panel on Climate Change]. (2018). *Global warming of 1.5°C*. Switzerland: Intergovernmental Panel on Climate Change. Retrieved from: ipcc.ch.

James, A. & Prout, A. (1990). *Constructing and Reconstructing Childhood*. Basingstoke: Falmer.

Jho, H., Yoon, H., & Kim, M. (2014). The relationship of science knowledge, attitude and decision making on socio-scientific issues: The case study of students' debates on a nuclear power plant in Korea. *Science & Education, 23*(5), 1131-1151.

Jickling, B. (1992). Why I don't want my children to be educated for sustainable development. *Journal of Environmental Education, 23*(4), 5–8.

Jungermann, H., Pfister, H.-R., & Fischer, K. (2005). *Die Psychologie der Entscheidung: Eine Einführung [The psychology of decision-making: An introduction]*. Heidelberg: Spektrum Akadischer Verlag.

Kachergis, G., Rhodes, M., & Gureckis, T. (2017). Desirable difficulties during the development of active inquiry skills. *Cognition, 166*(1), 407–417.

Kahn, S. & Zeidler, D. (2019). A conceptual analysis of perspective taking in support of socioscientific reasoning. *Science & Education, 28*(6/7), 605-638.

Kelly, P. (2006). Letter from the oasis: Helping engineering students to become sustainability professionals. *Futures, 38*(6), 696–707.

Ketterlin-Geller, L. R., Perry, L., & Adams, E. (2019). Integrating validation arguments with the assessment triangle: A framework for operationalizing and instantiating validation. *Applied Measurement in Education, 32*(1), 60–76.

Kinslow, A., Sadler, T., & Nguyen, H. (2019). Socio-scientific reasoning and environmental literacy in a field-based ecology class. *Environmental Education Research, 25*(3), 388-410.

Kolstø, S. D. (2001). 'To trust or not to trust,…': Pupils ways of judging information encoun-tered in a socioscientific issue. *International Journal of Science Education, 23*(9), 877–901.

Kopzhassarova, U., Akbayeva, G., Eskazinova, Z., Belgibayeva, G., & Tazhikeyeva, A. (2016). Enhancement of students' independent learning through their critical thinking skills development. *International Journal of Environmental & Science Education, 11*(18), 11585-11592.

Kuckartz, U. (2012). *Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung [Qualitative content analysis: Methods, practice, digital aid]*. Weinheim: Beltz-Juventa.

Kuckartz, U. (2014). *Mixed Methods: Methodologie, Forschungsdesigns und Analyseverfahren [Methodology, research designs and analysis]*. Wiesbaden: Springer VS.

Lane, S. & Iwatani, E. (2016). Design of performance assessments in education. In S. Lane, M. R. Raymond, & T. M. Haladyna (Eds.), *Handbook of test development* (pp. 274–293). New York, London: Routledge.

Lazer, D. M. J., Baum, M. A., Benkler, Y., Berinsky, A. J., Greenhill, K. M., Menczer, F., . . . Zittrain, J. L. (2018). The science of fake news. *Science, 359*(6380), 1094–1096.

Lee, Y. C. & Grace, M. (2010). Students' reasoning processes in making decisions about an authentic, local socio-scientific issue: Bat conservation. *Journal of Biological Education, 44*(4), 156–165.

Levy Nahum, T., Ben-Chaim, D., Azaiza, I., Herskovitz, O., & Zoller, U. (2009). Does STES-oriented science education promote 10th-grade students' decision-making capability? *International Journal of Science Education, 32*(10), 1315–1336.

Lewis, J. & Leach, J. (2006). Discussion of socio-scientific Issues: The role of science knowledge. *International Journal of Science Education, 28*(11), 1267–1287.

Lindahl, M., Folkesson, A.-M., & Zeidler, D. (2019). Students' recognition of educational demands in the context of a socioscientific issues curriculum. *Journal of Research in Science Teaching, 56*(9), 1155-1182.

Lindow, S. & Betsch, T. (2019). Children's adaptive decision making and the costs of information search. *Journal of Applied Developmental Psychology, 60*(1), 24–34.

Madsen, K. D., Nordin, L. L., & Simovska, V. (2016). Supporting structures for education for sustainable development and school-based health promotion. *Journal of Education for Sustainable Development, 10*(2), 274–288.

Marion, S. & Pellegrino, J. (2007). A validity framework for evaluating the technical quality of alternate assessments. *Educational Measurement Issues and Practice, 25*(4), 47–57.

Mayring, P. (2014). *Qualitative Content Analysis Theoretical Foundation, Basic Procedures and Software Solution*. Klagenfurt: SSOAR.

McBeth, W., & Volk, T. L. (2009). The national environmental literacy project: A baseline study of middle grade students in the United States. *The Journal of Environmental Education, 41*(1), 55–67.

McKeown, R., & Hopkins, C. (2016). Moving beyond the EE and ESD disciplinary debate in formal education. *Journal for Education in Sustainable Development, 1*(1), 17–26.

National Research Council. (2001). *Knowing What Students Know*. Washington, D.C.: National Academies Press.

Opfer, J., Nehm, R., & Ha, M. (2012). Cognitive foundations for science assessment design: Knowing what students know about evolution. *Journal of Research in Science Teaching, 49*(6), 744-777.

Oulton, C., Dillon, J., & Grace, M. M. (2004). Reconceptualizing the teaching of controversial issues. *International Journal of Science Education, 26*(4), 411–423.

Papadouris, N. (2012). Optimization as a reasoning strategy for dealing with socioscientific decision-making situations. *Science Education, 96*(4), 600–630.

Paraskeva-Hadjichambi, D., Hadjichambis, A., & Korfiatis, K. (2015). How students' values are intertwined with decisions in a socio-scientific issue. *International Journal of Environmental & Science Education, 10*(3), 493–513.

Paul, J., & Groß, J. (2017). Experimentation in science, engineering, and education. *International Refereed Journal of Engineering and Science, 6*(6), 322–327.

Paul, J., Lederman, N. G., & Groß, J. (2016). Learning experimentation through science fairs. *International Journal of Science Education, 38*(15), 2367–2387.

Pedaste, M., Mäeots, M., Siiman, L., Jong, T., van Riesen, S., Kamp, E., Manoli, C., Zacharia, Z., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review, 14*(1), 47-61.

Reitschert, K., & Hößle, C. (2007). Wie Schüler ethisch bewerten - Eine qualitative Untersuchung zur Strukturierung und Ausdifferenzierung von Bewertungskompetenz in bioethischen Sachverhalten bei Schülern der Sek. I [How students judge ethically - A qualitative study on the structure and differentiation of competence of moral judgement with respect to bioethical issues concerning students of Sek. I]. *Zeitschrift für Didaktik der Naturwissenschaften, 13*(1), 125–143.

Romine, W., Sadler, T., & Kinslow, A. (2017). Assessment of scientific literacy: Development and validation of the quantitative assessment of socio-scientific reasoning (QuASSR). *Journal of Research in Science Teaching, 54*(2), 274-295.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513–536.

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45*(1), 1–42.

Sadler, T. D. (2011). *Socio-scientific issues in the classroom: Teaching, learning and research.* Dordrecht: Springer.

Sadler, T. D., Barab, S, & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371-391.

Sakschewski, M., Eggert, S., Schneider, S., & Bögeholz, S. (2014). Students' socioscientific reasoning and decision-making on energy-related issues - Development of a measurement instrument. *International Journal of Science Education, 36*(14), 2291–2313.

Sartori, S., Da Silva, F. L., & Capos, L. (2014). Sustainability and sustainable development: A taxonomy in the field of literature. *Ambiente Sociedade, 17*(1), 1–22.

Seethaler, S. & Linn, M. (2004). Genetically modified food in perspective: An inquiry-based curriculum to help middle school students make sense of tradeoffs. *International Journal of Science Education, 26*(14), 1765–1785.

Siegel, M. A. (2006). High school students' decision making about sustainability. *Environmental Education Research, 12*(2), 201–215.

Simon, S. & Amos, R. (2011). Decision making and use of evidence in a socio-scientific problem on air quality. In. T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research.* (pp. 167-192). Dordrecht: Springer.

Sipos, Y., Battisti, B., & Grimm, K. (2008). Achieving transformative sustainability learning: Engaging head, hands and heart. *International Journal of Sustainability in Higher Education, 9*(1), 68–86.

Siribunnam, S., Nuangchalerm, P., & Jansawang, N. (2014). Socio-scientific decision making in the science classroom. *International Journal for Cross-Disciplinary Subjects in Education, 5*(4), 1777–1782.

Sleeter, C. E. & Flores Carmona, J. (2017). *Un-Standarizing Curriculum: Multicultural Teaching in the Standards-Based Classroom,* 2nd ed. New York: Teachers College Press.

Stefanou, C.R., Perencevich, K.C., DiCintio, M., & Turner, J.C. (2004). Supporting Autonomy in the Classroom: Ways Teachers Encourage Student Decision Making and Ownership. *Educational Psychologist, 39*(2), 97–110.

Sudman, S., Bradburn, N. M., & Schwarz, N. (1996). *Thinking about answers: The application of cognitive processes to survey methodology*. San Francisco: Jossey-Bass.

Thanh, N. C. & Thanh, T. (2015). The Interconnection Between Interpretivist Paradigm and Qualitative Methods in Education. *American Journal of Educational Science, 1*(2), 24–27.

Uskola, A., Maguregi, G., & Jiménez-Aleixandre, M.-P. (2010). The use of criteria in argumentation and the construction of environmental concepts: A university case study. *International Journal of Science Education, 32*(17), 2311–2333.

Wilson, R. & Keil, F. (2001). *MIT Encyclopedia of the Cognitive Sciences*. Cambridge: MIT Press.

Zeidler, D. (2014). Socioscientific issues as curriculum emphasis: Theory, research and practice. In N.G. Lederman & S. K, Abell (Eds.), *Handbook of research on science education, Volume II* (pp.679-726).

Zeidler, D., Herman, B. C., & Sadler. T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research*, *1*(11), 1-9.

Zeidler, D., & Nichols, B. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education*, *21*(2), 49-58.

6. STUDY 3

'I wouldn't want to be the animal in use nor the patient in need' – The role of issue familiarity in students' socioscientific argumentation[12]

Students' argumentation skills are considered a central tool to contribute to scientific controversies in the science classroom. Scientific controversies of social relevance (socioscientific issues; SSI) aim to derive meaning from authentic *issues* in which the science content occurs. Since SSI are inherently controversial, their debate is subject to multiple viewpoints and a variety of perspectives. The relationship between issue familiarity and students' multi-perspectival argumentation, however, is still a matter under discussion. Using a repeated measures design, this study contributes to this debate by exploring the effect of issue familiarity on students' multi-perspectival argumentation about a current SSI. Two research aims were central to this endeavor: (1) examining whether the selection of a particular issue (here: animal testing) enables students' engagement in multi-perspectival argumentation *without* additional issue familiarity; and (2) clarifying the relationship between *additional* issue familiarity and students' multi-perspectival argumentation. One hundred and sixty three ninth and tenth graders at public secondary schools located in Northern Germany participated in this intervention study. One hundred and six of them additionally took part in a 90-minute teaching unit to familiarize themselves with the issue. Students' written arguments on animal testing were collected using two open-ended items. The results of our study demonstrate that animal testing constitutes an effective issue to engage students with the complexity of SSI without requiring more than basic familiarity prior to engagement. In addition, the results indicate that an increased issue familiarity does not enhance the *diversity* of the perspectives that are manifested but rather the *depth* of these perspectives. This intensification was valid for value-based and knowledge-based (multidimensional) arguments as well as science- and economy-related (multidisciplinary) arguments.

Keywords: Argumentation, socioscientific issues, issue familiarity, animal testing

[12] This is a prior to peer-review version of the following manuscript: Garrecht, C., Reiss, M. J., & Harms, U. (in preparation). 'I wouldn't want to be the animal in use nor the patient in need' – The role of issue familiarity in students' socioscientific argumentation.

6.1. Introduction

One of the central goals in science education is to equip students with an understanding of science that then enables them to engage in science-related discussions that take place in their personal lives and in the wider society (DeBoer, 2000). This knowledgeability, subsuming all science learning experiences, is usually referred to as scientific literacy (Roberts & Bybee, 2014). Since the term's first occurrence in the late 1950s, there have been various attempts to define what aspects of knowledge, skills, and dispositions genuinely constitute a scientifically literate individual (Holbrook & Rannikmea, 2009). However, students' abilities to engage in argumentation have been considered an essential facet of scientific literacy from the beginning and this remains the case (Cavagnetto, 2010; Jiménez-Aleixandre & Erduran, 2008; KMK, 2004; NGSS, 2013; NRC, 2012; Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013).

Roberts (2007) reflected upon the different meanings of scientific literacy and distinguished between two understandings: Vision I and Vision II. According to Vision I, scientific literacy emphasizes processes and products within the disciplinary boundaries of science, conveying a knowledgeability that includes understanding a scientific issue "as a scientist would" (p.767). Science education in this perception aims at students mastering concepts and practices that are necessary for future scientists (Roberts & Bybee, 2014). In light of this vision, students' argumentation encompasses the construction and evaluation of evidence-driven arguments to address controversies *within* the science classroom (Erduran, Simon & Osborne, 2004; Ford, 2012). Advocates of Vision II, in contrast, emphasize that scientifically literate individuals should be able to apply their scientific understanding for the negotiation of science-related, real-world issues. In Vision II classrooms, argumentation thus represents a practice that integrates *diverse* viewpoints of both a social and a scientific nature to contribute to controversies *outside* the science classroom (Kolstø, 2001).

To promote this second and applied vision of scientific literacy, several curricular movements have emerged during recent decades (e.g., Science-Technology-Society [STS; Yager, 1993]; Science, Technology, Engineering, Arts, and Mathematics [STEAM; Colucci-Gray, Burnard, Gray & Cooke, 2019], socioscientific issues [SSI; Sadler, 2004]; see also Sadler & Zeidler, 2009). All of them, to a differing degree, aim to derive meaning from authentic *issues* in which the respective science content occurs (i.e. a particular science-related topic that is debated; Zeidler, Herman & Sadler, 2019). However, the relationship between the particular issue and students' argumentation is still a matter under discussion (Baytelman, Iordanou & Constantinou, 2020; Osborne, Henderson, MacPhersonm Szu, Wild & Yao, 2016; Sadler & Zeidler, 2004; Topcu, Sadler & Yilmaz-Tuzun, 2010; Udell, 2007).

Prior research has indicated that some issues seem to be more accessible for students than others (Christenson, Rundgren & Zeidler, 2014; Osborne et al., 2016; Udell, 2007). This highlights the importance of choosing suitable issues for teaching, especially if the outcome is to practice students' argumentation. Since teachers frequently report being challenged by short instruction time and a lack of pertinent materials (e.g., Lee, Abd-El Khalick & Choi, 2006; Pedersen & Totten, 2001; Zeidler, 2014), a suitable issue should preferably engage students in argumentation without requiring too much prior familiarity. In contrast to this practical demand, Baytelman and colleagues (2020) recently suggested that knowledge about the particular issue plays an important role in constructing arguments from multiple perspectives. The ability to identify and discuss arguments from different perspectives seems crucial, since SSI are inherently controversial (Sadler, Barab & Scott, 2007). Even though Baytelman et al. (2020) were able to explore this correlation due to their study's ex-post-facto-design, meaning that all data were collected in one session without an intermediate intervention, the causal effect of increased issue familiarity on multi-perspectival arguments remains unanswered.

To better understand how issue familiarity affects students' argumentation, two successive research endeavors will guide this paper. First, we will examine whether the selection of a particular issue (here: animal testing) enables students' engagement in multi-perspectival argumentation *without* additional familiarity. This first research step aims to add to knowledge about the accessibility of different issues. Secondly, this paper builds upon Baytelman and colleagues' (2020) promising evidence by further investigating students' multi-perspectival argumentation. To provide a clearer picture concerning the role of issue familiarity in students' argumentation, we expand Baytelman et al.'s previous insights by conducting an intervention study (pre-post-test design) to explore the missing link between the effects of increased issue familiarity on students' ability to argue from multiple perspectives.

6.2. Theoretical background

Promoting students' argumentation skills is a central element of science education (KMK, 2004; NGSS, 2013; NCR, 2012) and a prominent interest in science education research (e.g., Dawson & Carson, 2018; Simon, Erduran & Osborne, 2006; Zohar & Nemet, 2002). Argumentation describes a dynamic process of negotiation which promotes the (re-)construction of knowledge (Ford, 2008; Osborne & Patternson, 2011). In contrast to the process of reasoning, which describes an *internal* examination (Mercier, Boudry, Paglieri & Trouche, 2017), argumentation aims to communicate these considerations (Fischer et al., 2014; Means & Voss, 1996). In this sense, argumentation is understood as an external expression of prior reasoning (Sadler & Zeidler, 2005b; Schwarz & Asterhan, 2010). The argument, in turn, is the most central tool in an argumentation. Of the numerous scholars who have considered the elements of an argument, the work of two are presented here. Hoffmann (2016) characterizes an argument as "a premise-conclusion sequence so that either one or more premises are intended to support a conclusion or a conclusion is intended to be justified by one or more premises" (p. 369). Similarly, according to Walton (1990), an argument comprises "an externally manifested set of propositions 'designated' as premises and conclusions" (p. 400). Both definitions conceptualize an argument as a product (Hoffmann, 2018) that justifies a conclusion or assertion with at least one reason or support (Zohar & Nemet, 2002).

In science education, students’ ability to apply these propositions has received a lot of research attention (e.g., Evagorou, Jiménez-Aleixandre & Osborne, 2012; Faize, Husain & Nisar, 2018; Osborne, Erduran & Simon, 2004). The most dominant scheme for such evaluations, according to Chinn (2006), has been Toulmin’s Argument Pattern (TAP; Toulmin, 1958). TAP analytically exemplifies the different components of an argument with regards to data, warrant, backing, rebuttal, and claim. For the classroom, TAP has been successfully extended and modified by researchers such as Erduran et al. (2004) so as to measure the quantity and quality of students’ arguments in whole-class and small-group discussions. Besides TAP, scholars, including Schwarz et al. (2003), have developed further frameworks, aiming to evaluate the structure of students’ arguments – see Sampson and Clarke (2008), for an overview.

However, several shortcomings of TAP and comparable structure-focused schemes have been identified in recent years. Nussbaum (2011) and Nielsen (2013), for example, note that the dynamics of an argument, due to its dialogic nature, are lost when solely focusing on the structure of individual arguments. Sampson and Clark (2008) and Jafari and Meisert (2019) maintain that concentrating on the structural complexity of an argument largely overlooks its content and accuracy. As a result of this, recent studies have increasingly addressed this shortcoming and established various analysis frameworks that give more emphasis to the content of an argument. Such studies have researched various aspects of argumentation, ranging from students’ use of value statements (e.g., Grace, 2009) to the role of emotions (e.g., Basel, Harms, Prechtl, Weiß & Rothgangel, 2014; Polo, Lund, Plantin & Niccolai, 2016).

In science education, numerous of the content-oriented studies have focused on students’ argumentation in the context of SSI (Cavagnetto, 2010). SSI describe controversial social issues that are blended with science-related concepts and/or procedures (Sadler, 2011). SSI are unlike other issues that are traditionally addressed in the science classroom because they represent open-ended problems, meaning that a clear-cut and straightforward solution remains undetermined (Kolstø, 2006). The debate about these open-ended problems is, therefore, dominated in society by diverse interest groups (Sadler et al., 2007; Sadler & Zeidler, 2005a). As a result, different proposed solutions are subject to a variety of perspectives. Considering this authentic complexity presents an integral part of their negotiation which makes SSI “ideal topics for argumentation” (Zeidler & Sadler, 2007, p. 201).

The SEE-SEP model by Chang Rundgren and Rundgren (2010) constitutes an analysis framework for socioscientific argumentation that reflects the multi-perspectival complexity of SSI particularly well. The central idea of this model is to distinguish between diverse types of arguments that are used to negotiate this multi-perspectival complexity, including

(1) multidisciplinary and (2) multidimensional arguments. Both types will be described more detailed in the following.

On the one hand, according to Chang Rundgren and Rundgren, the complexity of SSI is due to the *multidisciplinary* concepts that are interwoven in the problem (Chang & Chiu, 2008). The debate about animal testing, as an exemplary SSI, draws from disciplines that include biology, politics, and ethics. Consequently, when students negotiate an SSI holistically, they must provide arguments that relate to different disciplines (Chang & Chiu, 2008; Christenson, Chang Rundgren & Höglund, 2012; Wu & Tsai, 2007). Through a review of the literature, the authors of the SEE-SEP model identified the most common disciplines in the negotiation of SSI: sociology/culture (So), environment (En), economy (Ec), science (Sc), ethics/morality (Et), and policy (Po).

On the other hand, the complexity of an SSI is also displayed in the existence of *multiple dimensions*: a descriptive and a normative one. This means issues cannot be negotiated solely by using appropriate knowledge (Osborne et al., 2004). It is also necessary to incorporate affective aspects to deal with these issues, which might be addressed in the form of past experiences. Since SSI are always related to real-world issues, students can make personal connections (Albe, 2008a; Chang & Chiu, 2008). In the socioscientific context of animal testing, students might have family members or acquaintances who depend on regular drug intake or other medical procedures that have been animal tested. Several empirical studies have documented students' use of these personal connections within their argumentation (e.g., Albe, 2008b; Sadler & Zeidler, 2004). The normative dimension of SSI can also be represented by the inclusion of personal values (Kolstø, 2006). To be aware of one's values might be particularly important in the case of SSI since these issues are inherently controversial. To critically reflect personal value propositions can, therefore, help students to make decisions in relation to these issues (Ratcliffe, 1997). Recently, many scholars have investigated students' use of value propositions within their arguments (e.g., Albe, 2008b; Christenson et al., 2012; Lee, 2007).

Besides this normative dimension, the descriptive dimension (here: knowledge) has equally been of interest when assessing the quality of argumentation. Theoretical and empirical work in the field of (science) education shows that students require certain basic knowledge in order to engage in argumentation (Lewis & Leach, 2006; Ogan-Bekiroglu & Eskin, 2012; Perkins & Salomon, 1989). However, previous studies reported differing findings as to whether more than basic knowledge improves the quality of student argumentation (for a review, see Sadler & Donnelly, 2006). On balance, the literature suggests that content knowledge does play a role in enhancing argumentation about SSI; however, the relationship might be non-linear. In an interview study, in which high school students had to argue about a genetic engineering issue, Sadler and Donnelly (2006) developed a "threshold model of content knowledge transfer" (p. 1482). A central aspect of this model is the distinction between three knowledge bases: basic knowledge, more advanced knowledge, and near expert knowledge. Students with near expert knowledge predominantly manifested increased argumentation quality, so it was concluded that a certain depth of knowledge was necessary before knowledge showed a positive effect on argumentation. A follow-up study by Sadler and Fowler (2006) empirically validated the robustness of this threshold model.

Other studies have further investigated the relationship between students' knowledge and the number of their arguments, hypothesizing that students with more robust knowledge will produce more arguments (Means & Voss, 1996; Schmidt, Rothgangel & Grube, 2015; 2017). Evagorou and Osborne (2013), for example, examined the number of claims in students' collaborative argumentation. They found that some groups proposed more claims than others, and this indicated students' ability to present more solutions for the issue in question. This quantitative increase, in turn, was interpreted as a more successful final product. A study by Sampson and Clark (2011) revealed similar results while exploring students' collaborative argumentation about a chemistry-related issue. Their analysis showed that "higher performing groups voiced twice as many unique content-related ideas […] as the less productive groups" (p. 76). This quantitative difference was subsequently suggested as a potential prerequisite for the production of high-quality argumentation. Summarizing these cases suggests that an increased number of arguments seem to indicate a more detailed elaboration of the underlying issue. This conclusion aligns with findings of a study by Lewis and Leach (2006), who found that students who were more familiar with the particular issue were also able to identify its key elements which, in turn, enabled them to engage in an in-depth discussion.

With a rising interest in the potential of SSI for science education, a variety of issues have been employed to explore students' argumentation practices and skills. These range from environmental issues (Evagorou & Osborne, 2013), through genetic engineering (Walker & Zeidler, 2007; Zohar & Nemet, 2002), to climate change (Dawson & Carson, 2018). Although this indicates the heterogeneity of investigated issues, there remains a lot of uncertainty about their impact on the quality of students' argumentation. While some studies conclude that reasoning patterns are consistent across issues (e.g., Romine, Sadler & Kinslow, 2017) other study results suggest the opposite claiming a certain issue-dependency (e.g., Topcu et al., 2010). Besides, previous research offers only preliminary insights into students' preferences and openness to engage with different issues (Osborne et al., 2016; Udell, 2007). Yet, most of the scholars in the field of science education agree that a basic familiarity with the scientific content of a SSI is needed to engage in argumentation (Baytelman et al., 2020; Grooms, Sampson & Enderle, 2018; Means & Voss, 1996; Osborne et al., 2016; Sadler & Zeidler, 2004; Topcu et al., 2010, von Aufschnaiter, Erduran, Osborne & Simon, 2008).

From an empirical point of view, most of the studies that paid attention to the role of the issue under consideration analyzed students' arguments regarding their logical structure (e.g., using tools such as Toulmin's TAP, 1958). However, as mentioned, the ethical and factual complexity of SSI might become lost when relying solely on such structure-focused schemes. This gap has been addressed by Baytelman and colleagues (2020) who investigated the relationship between university students' content knowledge, epistemic beliefs and socioscientific argumentation. Instead of merely inquiring about the structural components of students' arguments, the authors were also interested in their content-related diversity (namely: arguments from social, ethical, economic, scientific, and ecological perspectives). As a result, they concluded that a familiarity with the topic seems crucial "not only for the quantity and quality of arguments but also for the diversity of different types of arguments that students construct, in their effort to take into consideration multiple sides and perspectives of a socioscientific topic" (p.22). Yet, the question of whether increased issue familiarity affects the diversity of the arguments that are employed remains unanswered, due to their study's ex-post-facto-design.

6.2.1. Socioscientific argumentation about animal testing

Although there remains a lot of uncertainty about the relationship between particular issues and students' negotiation of them, it has been suggested that some issues might be easier for students to engage with than others (Christenson et al., 2014; Osborne et al., 2016; Udell, 2007). As part of this study, we propose animal testing as a particularly powerful issue to engage students in multi-perspectival argumentation. Our rationale for this choice can be explained along the following lines.

(a) Animal testing serves as a topic that captures the inherent complexity of SSI (multidisciplinary and multidimensional aspects) particularly well.

First of all, discussing whether or not animal testing is justified requires the integration of *multidisciplinary* perspectives, such as scientific (e.g., knowledge extraction), ethical (e.g., the integrity of life), economic (e.g., costs), social (e.g., medical development) and environmental (e.g., toxicology) aspects. In addition, in contrast to other socioscientific issues, such as climate change and nuclear power, which require students' understanding of physical, chemical, and biological concepts, the scientific links connected to animal testing are limited to the broader discipline of biology. This cognitive reduction might increase the topic's accessibility to a greater number of students.

Then there is the fact that making an informed decision about the acceptability of animal testing requires the consideration of *multidimensional* aspects. First, students need a certain amount of knowledge (e.g., transferability of data obtained from mice to humans, where the laboratory mouse serves as a model for humans: descriptive dimension). Secondly, students must be able to reflect on ethical implications (e.g., the integrity of life: normative dimension).

(b) Due to animal testing's indirect presence in our everyday life (e.g., the debate concerning vaccination) as well as its more tangible aspects (e.g., health-related dependency on drug developments), this issue can be particularly meaningful for students. We further presume that students connect with this issue particularly well because topics that surround the well-being of animals are emotionally fraught (Holsterman, Grube & Bögeholz, 2009). This, in turn, can evoke students' emotive resources which might positively affect their motivation for engagement (Hidi & Renninger, 2006) and further support a fruitful discourse (Polo et al., 2016).

(c) Animal testing receives a lot of media attention. The recent publication of undercover footage from animal testing laboratories in Germany (Hamburg), the Netherlands (Rijswijk), and the USA (New Mexico), for example, has stirred up public debate about the conditions and practices found on the videos. In contrast to this opposition on animal testing, the current global health crisis resulting from COVID-19 requires animal testing in attempts to develop of a vaccine. For such reasons, students might be not only have a basic familiarity with the issue but also be interested to engage in discussion about it.

(d) Albe (2008b) advocates the deployment of issues that encourage students to examine the production of scientific knowledge, the possibilities and limitations of scientific inquiry, and the social responsibility of science. Animal testing is an issue that can address this demand. Given the substantial ethical implications of this issue, employing an SSI approach offers students the opportunity to explore the relationship between scientific procedures and their social connotations.

Altogether, animal testing seems likely to serve as a very suitable SSI to stimulate students' multi-perspectival argumentation, due to its relevance for the society as a whole and each individual, its presence in the media, and its emotive nature (see also Marks & Eilks, 2009).

6.3. Research aims

The main objective of this study was to extend current knowledge by gaining a fuller understanding of the relationship between issue familiarity and students' multi-perspectival argumentation about a current SSI. First, we investigate whether animal testing presents an effective issue that engages students in multi-perspectival argumentation (where they employ multidisciplinary and multidimensional arguments) *without* additional issue familiarity. This first research step thus aims to add to what is known about the suitability of different issues for enabling students to engage in high-quality argumentation in science classrooms. Secondly, we examine the effect of issue familiarity on students' multi-perspectival argumentation. This paper builds upon Baytelman et al.'s (2020) previous findings by examining the role of issue familiarity on the diversity of students' arguments. Similarly to Baytelman and colleagues, we will concentrate on diverse disciplines (here: social, environmental, economic, scientific, ethical, and political). In addition, we will distinguish each argument with regards to its normative or descriptive dimension (here: knowledge, value, experience).

6.4. Methods

6.4.1. Research design

In order to address the previously established objective, this research follows a quasi-experimental pre-post-test design with control group (see Figure 6.1). Our first step was to develop a teaching unit that gives students the opportunity to familiarize themselves with the issue (here: animal testing, see 6.4.2.). Next, we developed two open-ended items, intended to engage students in socioscientific argumentation about animal testing (see 6.4.3.). Students' written arguments were analyzed using the SEE-SEP model of Chang Rundgren and Rundgren (2010, see 6.4.5.). To draw conclusions about a possible increase in issue familiarity due to participation in the teaching unit, we also assessed the number of arguments that were produced by students. Each step of the study design process will be discussed in more detail below.

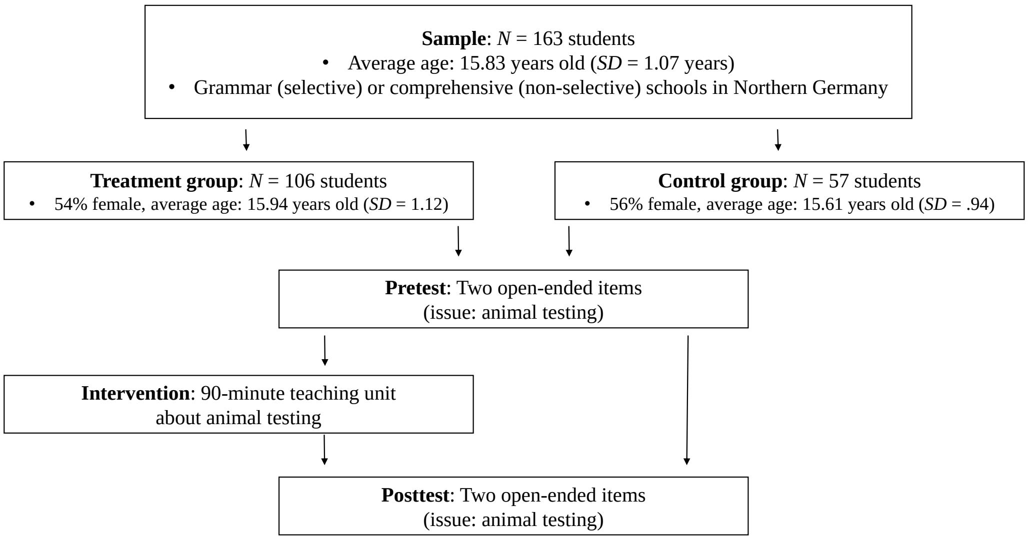

Figure 6.1: Overview of the study design.

6.4.2. The development and structure of the teaching unit

To increase students' familiarity with the issue, we developed a teaching unit. The structure and content of this unit were built upon a previously developed catalog of criteria. This catalog distinguishes 16 independent criteria (e.g., objectivity, changing perspectives, positioning) that can be used by teachers and researchers alike to assess the quality of animal testing-related teaching materials. Each criterion was checked for necessity and subject to refinement through expert rating. All experts (n = 44) were either from the field of science education research or conducting animal testing themselves. Based on this catalog, we then developed a 90-minute biology unit for upper secondary school students.

The design of this teaching unit features essential characteristics of SSI-based instruction construct (Presley et al., 2013; Sadler, Foulk & Friedrichsen, 2017). This involved, amongst other things, students' confrontation with a compelling real-world issue (here: animal testing), students' engagement in scientific higher-order practices (here: reasoning, argumentation, and decision-making), and a culminating activity to connect and situate students' learning (here: group discussion). In addition to these design elements, open-mindedness and mutual respect were communicated at the beginning of the unit for a beneficial learning environment. To visualize the inherent complexity of this issue, various arguments from multiple perspectives were presented and discussed during the 90-minute teaching unit. Table 6.1 presents the three interconnected parts of the intervention.

Table 6.1: Structure and content of the teaching unit. Main learning activity of each part in bold.

Overall learning aim: Each student will (1) recognize animal testing as an ethical dilemma, (2) acknowledge and develop arguments from diverse perspectives, and (3) explore their own view on this issue.

Part	Overarching task	Learning activity
Preparation	Read background information. *Sources*: Deutsches Referenzzentrum für Ethik in den Biowissenschaften [German Reference Centre for Ethics in the Life Sciences]; Tierversuche verstehen [Understanding animal testing]; Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz [BMEL; Federal Ministry of Food and Agriculture]; Deutsche Forschungsgemeinschaft [DFG; German Research Foundation]; Palm & Keller (2017); Stiftung für das Tier im Recht [TIR; Center of Excellence for Animals in Law, Ethics and Society].	The homework was administered to ensure that all students have a basic familiarity with the issue at the beginning of the teaching unit. The homework informed students about the procedure, implications, and legal situation. It was set and undertaken after the pretest and at least seven days before the actual intervention. Task: "Read the text and highlight statements that seem important for a debate about animal testing."
Part 1:	Exploring the dilemma behind animal testing	"Pictures on a wall" (flashlight activity: recognition of intuitive thoughts and feelings towards animal testing). "Chain of information" (sorting slips of paper: refresh background information from homework). "**Role play**" (recognize two different perspectives on animal testing).
Part 2:	Exploring different perspectives on animal testing (for or against, and everything in-between)	"What are the options?" (addressing the diverse courses of action). "**Worksheet: diverse arguments**" (exploring diverse arguments for and against animal testing, working out the underlying values).
Part 3	Exploring one's personal stance in this matter and taking part in a structured discussion	"What is more important?" (sorting and weighting arguments with respect to one's own views). "Where to put your sticker" (anonymously mapping one's personal opinion towards animal testing on a poster). "**Group/Classroom discussion**" (partaking in group/classroom debate).

The teaching unit strictly followed the schedule of activities presented in Table 6.1 to ensure comparability between classes. In addition, teaching protocols were written by a teaching assistant in an attempt to control for any discrepancies in the delivery of the teaching unit.

6.4.3. Item development and data collection

Two open-ended items, along the lines of Christenson, Chang Rundgren and Zeidler (2014) and specific to the issue of animal testing, were designed to investigate students' argumentation (see Table 6.2). Prior to data collection, both items were piloted in three subsequent rounds with n = 119 participants (1^{st} round: *n* = 37 university students with a major in education, philosophy and biology from Schleswig-Holstein and Baden-Württemberg, *M* = 23.6 years, *SD* = 3.08 years; 2^{nd} round: *n* = 76 German citizens, *M* = 32.7 years, *SD* = 11.5 years; 3^{rd} round: *n* = 6 pupils, *M* = 14.8 years, *SD* = 0.69 years). Each round of piloting focused on the items' language (e.g., neutral wording), content (e.g., age-appropriateness) and structure (e.g., clarity).

Table 6.2: Description of two context-specific items used to investigate students' socioscientific argumentation.

Item number	Description of item	Item task
Item 1	The item requires students to imagine that there will be a poll about the banning of animal testing.	"Imagine there is to be a poll about the banning of animal testing in Germany. Would you be for or against the banning of animal testing? Choose one side and state at least three arguments for your chosen view."
Item 2	Regarding item 1, item 2 reminds students that there are people who have different views to them about whether or not animal testing is acceptable.	"There are people who have different views to you about whether animal testing is acceptable. What sorts of people might these be and what arguments might they use to back up their opinions?"

As our study involved human participants, ethical approval was obtained from the Ministry for Education prior to data collection. Participation in the study was voluntary. All participants and parents were provided with information about the survey beforehand. Parents had to sign an informed consent form for their children to participate. Data were collected in 2018, between May and July. The questionnaire which included both items (see Table 6.2) was filled in by students using netbooks that were provided by the authors of this study. The data were anonymized during collection since all participants were instructed to create a predefined code to match the pre- with the posttest files. Students spent approximately 20 minutes in total on both tasks.

6.4.4. Sample

The sample (*n* = 163 students; *M* = 15.83 years; *SD* = 1.07 years) were aged between 15 and 18 years and attended either grammar (selective) or comprehensive (non-selective) schools in Northern Germany. The treatment group consisted of *n* = 106 students (54% female, mean age = 15.94 years; *SD* = 1.12 years) and participated in the teaching unit (see 6.4.2.). These students were asked to answer both items (see Table 6.2) before and after the intervention. The second group of students, who functioned as a control group, consisted of *n* = 57 students (56% female, mean age = 15.61 years; *SD* = .94 years). This group did not participate in the teaching unit, having instead regular teaching. The control group answered the same two items at the same measurement points as the treatment group.

6.4.5. Data analysis

The two open-ended, context-specific items were implemented to examine students' multi-perspectival argumentation. The SEE-SEP model served as an analysis scheme to document students' ability to unravel the complexity of an SSI (here: animal testing; Chang Rundgren & Rundgren, 2010). This complexity was conceptually divided into students' use of multidisciplinary perspectives (So, En, Ec, Sc, Et, and Po) and incorporation of multidimensional aspects (knowledge, values, and experience) within their socioscientific argumentation. All of the arguments generated in this study were analyzed individually. Each of the arguments was assigned to one of the 18 codes of the SEE-SEP model (see Table 6.3). A more in-depth description of the SEE-SEP analysis scheme, as well as examples of coding, can be found in Chang Rundgren and Rundgren (2010).

Table 6.3: Codes of the SEE-SEP model's analysis scheme (Chang Rundgren & Rundgren, 2010; Christenson et al., 2014).

Subject area / Aspects	Knowledge (K)	Value (V)	Personal Experience (E)
Sociology/culture (So)	SoK	SoV	SoE
Environment (En)	EnK	EnV	EnE
Economy (Ec)	EcK	EcV	EcE
Science (Sc)	ScK	ScV	ScE
Ethics/morality (Et)	EtK	EtV	EtE
Policy (Po)	PoK	PoV	PoE

After coding, the interrater reliability was calculated to assure the reliability of the results. The interrater reliability was found to be good (Cohen's κ = .79).

6.5. Findings

6.5.1. Number of arguments

In total, 1318 arguments were generated (pretest: 610; posttest: 708). A repeated measures ANOVA showed that the mean number of arguments differed significantly between the two measurement times ($F(1, 161) = 6.34$, $p = .013$, $\eta_p^2 = .038$). A statistically significant interaction between time and groups indicated that the use of arguments depends on the group affiliation ($F(1, 161) = 19.61$, $p < .001$, $\eta_p^2 = .11$) (Figure 6.2). Additionally, the main effect for the treatment group was statistically significant ($F(1, 161) = 11.55$, $p = .001$, $\eta_p^2 = .067$). The means and standard deviations for pre- and posttest and both groups are presented in Table 6.4.

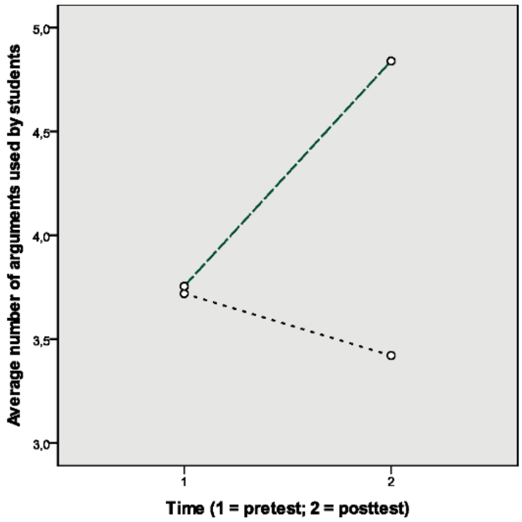

Figure 6.2: Number of students' arguments in pre-and posttest (dashed lines: treatment group; dotted: control group).

Table 6.4: The means and standard deviations of relevant variables for pre- and posttest for both groups.

	Treatment group		**Control group**	
	Pretest	Posttest	Pretest	Posttest
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Sociology/culture-related	0.35 (0.60)	0.32 (0.54)	0.37 (0.56)	0.37 (0.59)
Economic-related	0.23 (0.44)	0.45 (0.68)	0.25 (0.47)	0.23 (0.46)
Environment-related	0 (0)	0 (0)	0 (0)	0.02 (0.13)
Science-related	1.03 (0.81)	1.61 (1.16)	0.91 (0.74)	0.77 (0.66)
Ethics/morality-related	2.09 (1.14)	2.29 (1.12)	2.11 (1.11)	1.96 (0.96)
Politics-related	0.07 (0.25)	0.19 (0.42)	0.07 (0.26)	0.11 (0.31)
Knowledge-based	0.68 (0.75)	1.16 (1.22)	0.49 (0.66)	0.4 (0.65)
Value-based	3.08 (1.28)	3.71 (1.47)	3.19 (1.48)	3.02 (1.42)
Experience-based	0.01 (0.1)	0 (0)	0.02 (0.13)	0.04 (0.19)
Total number of arguments	3.75 (1.41)	4.84 (1.97)	3.72 (1.49)	3.42 (1.31)

6.5.2. Students' multi-perspectival argumentation

To enable deeper insight into the diversity of perspectives used in students' argumentation we investigated students' use of multidisciplinary (So, Ec, En, Sc, Et, Po) and their use of multidimensional (knowledge, value, and experience) arguments.

6.5.2.1. Use of multidisciplinary arguments

A multivariate test (MANOVA) was conducted to examine associations between the different variates (So, Ec, En, Sc, Et, Po). For the calculation, the change in the number of discipline-dependent arguments from before to after the intervention was used. Across all variates, there was a statically significant difference in the use of discipline-dependent arguments ($F(6, 156) = 4.59$, $p < .001$, $\eta_p^2 = .15$).

In particular, univariate testing indicated that partaking in the teaching unit shows a statistically significant effect on the use of science-related ($F(1, 161) = 14.76$, $p < 0.001$, $\eta_p^2 = .084$) and economy-related ($F(1, 161) = 4.36$, $p = .038$, $\eta_p^2 = .026$) arguments (see Table 6.5). For the other variates, the effect failed to reach statistical significance. The mean and standard deviation for pre- and posttest and both groups are presented in Table 6.4.

Table 6.5: Results of univariate testing (multidisciplinary arguments).

Disciplines	df	Mean square	F	Sig.	Partial Eta-square
Society	1	.03	.067	.795	.000
Economy	1	2.206	4.356	.038	.026
Environment	1	.011	1.87	.173	.011
Science	1	19.497	14.764	.000	.084
Ethics	1	4.246	2.498	.116	.015
Politic	1	.284	1.96	.163	.012

Following those significant effects, simple effects analyses were conducted (Figure 6.3). For science-related arguments, the test showed that there was significant development *within* the treatment group from pre- to posttest ($F(1, 161) = 27.46$, $p < .001$, $\eta_p^2 = .146$). This was not the case for the control group ($F < 1$). It could also be shown that in the posttest there was a significant difference *between* both groups ($F(1,161) = 25.57$, $p < .001$, $\eta_p^2 = .137$) which was not found in the pretest ($F < 1$).

For economy-related arguments, the test showed that there was significant development *within* the treatment group from pre- to posttest ($F(1, 161) = 10.73$, p = .001, $\eta_p^2 = .062$) but not in the control group ($F < 1$). In addition, there was a significant difference in the posttest *between* both groups ($F(1, 161) = 5$, $p = .027$, $\eta_p^2 = .03$) which was not the case in the pre-test ($F < 1$).

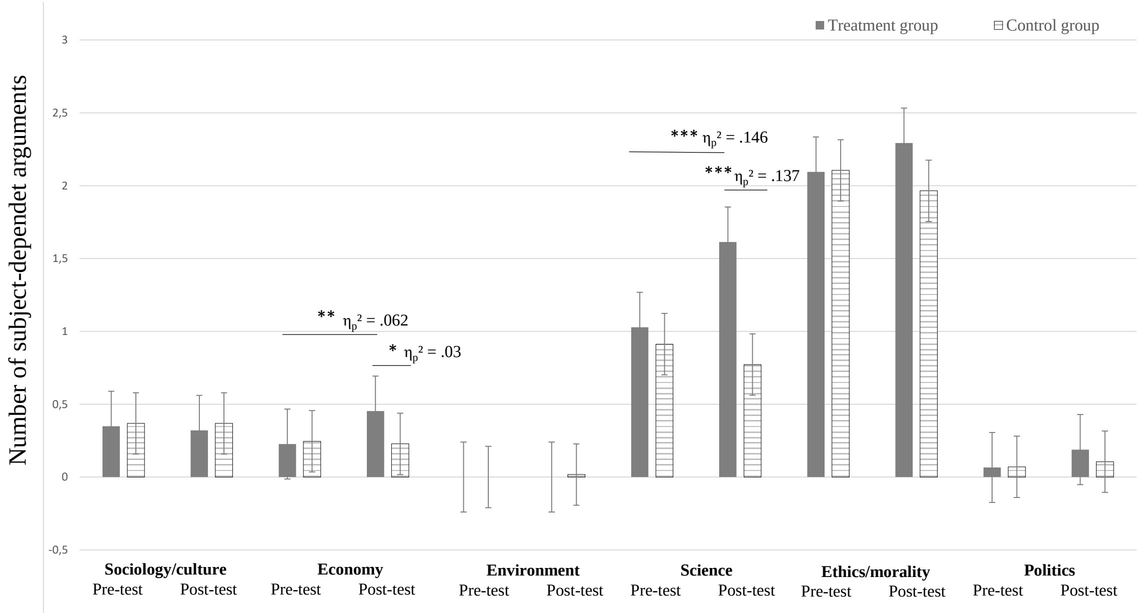

Figure 6.3: Use of multidisciplinary arguments compared between treatment and control group in pre- and posttest.

6.5.2.2. Use of multidimensional arguments

The same variables were used to investigate the development of multidimensional arguments. A second MANOVA was conducted to examine associations between the variates (knowledge, value, and experience). For the calculation, the change in the number of arguments from before to after the intervention was used. Across all variates, there was a statically significant difference in use of multidimensional arguments ($F(3, 159) = 7.4$, $p = < .001$, $\eta_p^2 = .112$).

In particular, univariate testing indicated that partaking in the teaching unit had a statistically significant effect on the use of knowledge-related ($F(1, 161) = 9.42$, $p = .003$, $\eta_p^2 = .056$) and value-related ($F(1, 161) = 9.91$, $p = .002$, $\eta_p^2 = .058$) arguments (see Table 6.6). The mean and standard deviation for pre- and posttest and both groups are presented in Table 6.4.

Table 6.6: Results of univariate testing (multidimensional arguments).

Aspect	df	Mean square	F	Sig.	Partial Eta-Square
Knowledge	1	11.995	9.419	.003	.055
Value	1	24.171	9.905	.002	.058
Experience	1	.027	1.093	.297	.007

Following those significant effects, simple effects analyses were conducted (Figure 6.4). For knowledge-related arguments, the test showed that there was significant development *within* the treatment group from pre- to posttest ($F(1, 161) = 19.27$, $p < .001$, $\eta_p^2 = .107$).

This was not the case for the control group (*F* <1). The results also yielded a significant difference in the posttest *between* both groups ($F(1,161) = 21.23$, $p < .001$, $\eta_p^2 = .106$) which was not the case in the pre-test ($F(1, 161) = 2.53$, $p = .11$).

For value-related arguments, the results indicated significant development *within* the treatment group from pre- to posttest ($F(1, 161) = 17.35$, $p < .001$, $\eta_p^2 = .097$) but not in the control group ($F < 1$). Also, there was a significant difference in the post-test *between* both groups ($F(1, 161) = 8.38$, $p = .004$, $\eta_p^2 = .049$) which was not the case in the pre-test ($F < 1$).

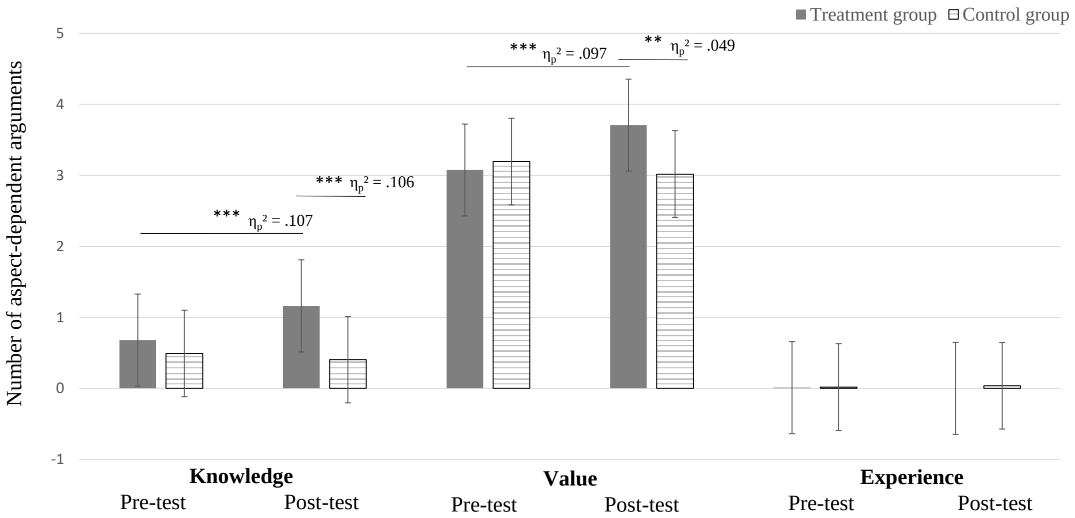

Figure 6.4: Use of multidimensional arguments compared between treatment and control group in pre- and posttest.

6.6. Discussion

Vision II scientific literacy encompasses, first, a student's capacity to identify science-related social issues and, secondly, to evaluate and express their own view in a multi-perspectival manner (Holbrook & Rannikmae, 2009). In exposing students to SSI, it is presumed that students recognize the complexity that derives from the particular issue, encouraging them to translate this diversity of perspectives into their subsequent argumentation (Sadler, et al., 2017). The main objective of this study was to extend the current literature by gaining a better understanding about the relationship between students' socioscientific argumentation and issue familiarity. First, we examined whether animal testing presents an effective issue that engages students in socioscientific argumentation *without* additional familiarity. Secondly, we assessed the effect of issue familiarity on students' socioscientific argumentation. Similar to Baytelman et al. (2020), we analyzed students' arguments in terms of *discipline* relations (here: social, environmental, economic, scientific, ethical, and political) and, in addition, we distinguished each argument with regards to its normative or descriptive *dimension* (here: knowledge, value, experience).

6.6.1. Animal testing as an effective issue for argumentation

Even though the body of work on the significance of particular issues for argumentation is rather limited, previous studies have suggested that some issues might be easier for students to engage with than others (Christenson et al., 2014; Osborne et al., 2016; Udell, 2007). At the same time, a range of studies has documented teachers' challenges regarding SSI instruction, including formal obstacles such as limited instruction time and a lack of pertinent materials (Lee et al., 2006; Pedersen & Totten, 2001; Zeidler, 2014). A suitable issue should therefore, if possible, engage students in argumentation without requiring too much prior issue familiarity. As part of this study, we proposed animal testing as a potentially particularly effective issue to engage students in socioscientific argumentation even *without* additional issue familiarity. To evaluate this assumption, students' arguments from the pretest were central to the analysis.

The analysis of our data indicates that students were able to utilize a reasonable number of multidisciplinary and multidimensional arguments *before* participating in the teaching unit. This implies that animal testing constitutes a suitable issue to engage students with the complexity of an SSI without requiring too much prior familiarity. A basic familiarity with the topic is likely, due to its presence in the media, for example (see 6.2.1.). This supports the broad consensus within the science education community that a basic familiarity with an issue is necessary for students to engage in argumentation about it (e.g., Grooms et al., 2018; Osborne et al., 2016; Sadler & Zeidler, 2004; Topcu et al., 2010, von Aufschnaiter et al., 2008). Furthermore, this result reflects students' general interest in engaging in a discussion about this particular issue. Similar observations reporting students' genuine interest to debate animal testing have been made in other studies (e.g., Agell, Soria & Carrió, 2014; France & Birdsall, 2015).

6.6.2. Relationship between issue familiarity and argumentation

As its main focus, this paper examines the effect of issue familiarity on students' multi-perspectival argumentation. To evaluate students' issue familiarity subsequent to the teaching unit, the occurrence of a greater number of arguments was used as an indicator for a more familiarized elaboration of the underlying issue.

6.6.2.1. The number of arguments as an indicator for increased issue familiarity

The first step sought to investigate a quantitative development of proposed arguments to estimate students' increased issue familiarity due to participation in the teaching unit. The results of our study show that the treatment group used significantly more arguments after the intervention in comparison to the pretest and the control group. Similar to the interpretation of other scholars, we interpret the increase in arguments as indicating a more elaborate consideration of the issue (see also Evagorou & Osborne, 2013; Means & Voss, 1996; Schmidt et al., 2015; 2017). The present data are also consistent with findings by Lewis and Leach (2006) who implemented learning activities about a bioethical issue (gene technology) to explore students' socioscientific argumentation. One of their findings indicated that students were able to engage in a more thorough discussion once they were more familiar with the issue and thus were able to identify the issue's key aspects.

6.6.2.2. The relationship between issue familiarity and diversity of arguments

For a more complete understanding regarding the role of issue familiarity on students' proposed argument types (here: multidisciplinary and multidimensional arguments), the development of students' arguments from the pre- to posttest was central to the data analysis. In contrast to our expectations, the results of this study indicate that an increased issue familiarity does not enhance the *diversity* of arguments; however, the *depth* of treatment of existing disciplines and dimensions was enhanced. This finding, namely the intensifying role of issue familiarity, extends the result of Baytelman et al. (2020), who suggested a relationship between issue familiarity and diversity of arguments. This novel insight has to be considered from two positions.

On the one hand, this finding potentially indicates that students were able to draw upon more discipline-related concepts and knowledge subsequent to the teaching unit, which possibly enabled them to strengthen their previous arguments (Haro, Noroozi, Biemans & Mulder, 2020; Nielsen, 2011; von Aufschnaiter et al., 2008). Following this line of reasoning, one important factor might have been students' participation in the group/classroom discussion. Even though group discussions can have severe limitations, e.g., students ganging up on each other or taking extreme or under-explained positions in the debate (Kutnick & Roger, 1994), they offer opportunities. First, possible cognitive conflicts that arose during the debate might have forced students to adjust their conceptual understanding and, eventually, lead to increases in their learning in a certain topic area (Dawes, 2004; Jafari & Meisert, 2019; Mercier & Sperber, 2011; Nussbaum & Sinatra; 2003). Secondly, students' dynamic exchange of ideas can enable them to practice justifying and defending their claims, check their arguments for efficacy and internal strength, and address contradictory points (Jafari & Meisert, 2019; Mercier et al., 2017; Sadler, 2004). These opportunities could have helped students to validate and strengthen their previous arguments with further discipline-related evidence.

On the other hand, the deepening of previously manifested disciplines and dimensions has to be viewed critically. One of the main reasons why educators advocate the implementation of SSI is students' authentic experience with controversial issues. This is also reflected in didactic suggestions, as noted in Kahn and Zeidler (2017), highlighting that students' introduction to different perspectives of an issue is a central part of the teaching approach. Considering an SSI from multiple perspectives is held to improve the quality of learners' decision-making (Chang & Rundgren, 2010; Lee et al., 2019; Lindahl, Folkesson & Zeidler, 2019, Wu & Tsai, 2007) and further reflects students' depth of reasoning (Nussbaum & Schraw, 2007). Based on these theoretical and empirical propositions, we offered students several opportunities during our 90-minute teaching unit to explore the different perspectives that pervade animal testing. Yet, our results indicate that students strengthened their previously manifested view instead of considering a greater variety of perspectives.

One possible explanation for students' lack of a greater diversity of perspectives might be derived from a psychological stance, suggesting that students, especially when unused to engaging in argument, keep to their previous views in order to avoid cognitive overload (Kuhn & Udell, 2003). The tendency to stick with previous argumentation patterns has also been shown in several other studies reporting students' general difficulty in changing perspectives within an argument (e.g., Evagorou et al., 2012; Kuhn, 2008; Nielsen, 2011). In the study by Evagorou et al. (2012), for example, students' written arguments on a local animal-related SSI (red vs. grey squirrels) were investigated. One of their main findings was that students primarily used evidence that supported their previously manifested position while ignoring contradictory information. This observation suggests that students applied something like a 'selective focus' on what information should be implemented into their socioscientific argumentation. This 'selective focus' might be evident in our study, indicating that students might behave in a similar selection mode regarding evidence from particular disciplines or dimensions. When, for example, some students perceive science-related arguments as more purposeful and conforming with their arguments than ethical arguments, they might end up predominantly considering this kind of evidence during the teaching unit, simply because it fits with their preference. Manifesting one's previous perspectives, according to Schmidt et al. (2017), also has a counteractive notion since it is reference to diverse disciplines "which gives students an advantage in discussing complex topics" (p. 104). In their studies (2015; 2017), Schmidt and colleagues revealed that diverse knowledge across several disciplines not only advantaged students' short-term argumentation but also helped them to recall arguments on later occasions. This finding seems important, given that students should also be able to engage and shape controversies *outside* the science classroom.

While previous research already suggested that students tend to keep the arguments they made initially (e.g., Chang & Chiu, 2008; Driver, Newton & Osborne, 2000), our results not only support this conclusion but show that this is also true for the disciplines and dimensions that students use in their argumentation. Taking this point of view, merely increasing issue familiarity while presenting different perspectives does not seem to be enough to enhance the diversity of arguments used by students. More instructional guidance, for example tools such as illustrated charts and maps of possible perspectives (e.g. Ke, Sadler, Zangori & Friedrichsen, 2020), might be needed to actively support students to increase their diversity of perspectives.

Last but not least, our finding further indicates that some types of arguments seem to be interpreted by students as more expedient than others in this particular issue. It seems reasonable to investigate these specific disciplines and dimensions in more detail, but not with the presumption that any one discipline or dimension is more valuable or desirable in students' argumentation than another. The analysis of our data revealed a significant increase in value-based and knowledge-based (multidimensional) as well as science-related and economy-related (multidisciplinary) arguments subsequent to the teaching unit.

6.6.2.2.1. Multidisciplinary arguments

Concerning students' use of multidisciplinary arguments, we found a statistically significant increase in the use of science-related arguments within the treatment group. These findings contradict prior studies which suggest that students feel challenged to propose science- and technology-oriented arguments in SSI-contexts (e.g., Lewis & Leach, 2006; Wu & Tsai, 2007). Wu and Tsai (2007), for example, explain this lack on the grounds that students are unable to connect the scientific knowledge they have learned in school science with the negotiation of authentic SSI. Our findings, in contrast, provide evidence that students enhanced their ability to use science-related arguments when negotiating the SSI of animal testing. This affirms the overall conclusion that animal testing serves as an effective SSI.

Animal testing also needs to be considered from an economic view. On the one hand, using animals in research incurs high financial costs, e.g., the keeping of the animals. On the other hand, it has an economic impact on associated companies and industries (e.g., the pharma industry; Meigs Smirnova, Rovida, Leist & Hartung, 2018). Regarding the use of economy-related arguments, the findings of this study suggest a statistically significant increase due to participation in the teaching unit. A possible interpretation of this finding is an observation that was made during the teaching of the unit, where students frequently referred to the financial costs and benefits of animal research. Participants' ability to identify this argument should be acknowledged because it emphasizes their understanding that commercial interests can often be a driver or barrier for change (Gruber & Hartung, 2004).

6.6.2.2.2. Multidimensional arguments

The present data provide evidence that students frequently used value-based arguments in their negotiation. Furthermore, the findings suggest that the use of value-based arguments significantly increased after participation in the teaching unit. We will put forward two arguments in an attempt to explain this. On a more general level, the inherently complex structure of SSI requires the recognition of normative foundations (Osborne et al., 2004). It has been demonstrated in several empirical studies that students showed no difficulties in addressing some of the underlying values and norms of the discussed SSI, even though no explicit teaching about these had been undertaken (e.g., Christenson et al., 2012; Christenson et al., 2014). This might be one argument for the high number of value-based arguments found in our pretest. The present finding confirms the vital role of a normative dimension in students' negotiation of SSI (e.g., Albe, 2008b; Chang Rundgren & Rundgren, 2010; Lee, 2007). On a more issue-related level, animal-related issues seem to be emotionally salient for students (Kalvaitis & Monhardt, 2015; Reiss, 2017). This salience might be due to a shared connection between students and animals (e.g., pet-keeping), the more instrumental purposes of animals (e.g., source of food), empathy or ethical sensitivity (Amiot, Bastian & Martens, 2016). As a result, it is not that surprising that value-laden arguments are often interwoven into the negotiation of animal-related SSI (e.g., Birdsall & France, 2011; Holstermann, Grube & Bögeholz, 2009).

The results of this study also yielded a statistically significant relationship between the teaching unit and students' use of knowledge-based arguments. As shown in previous research, a certain amount of knowledge is necessary to discuss an issue on a basic level (e.g., Lewis & Leach, 2006; Monteiro, Sherbino, Sibbald & Norman, 2019; Ogan-Bekiroglu & Eskin, 2012). It was, therefore, not surprising to find knowledge-based arguments in students' pretest data. In the posttest of this study, we found a statistically significant increase in the use of knowledge-based arguments in the treatment group. Students' use of knowledge-based arguments has been interpreted to substantiate the negotiation of an SSI (Sadler & Zeidler, 2005b). The significant increase of knowledge-based arguments within this study thus suggests a positive development which is likely to support the quality of students' argumentation. Moreover, the group/classroom discussion at the end of the teaching unit seems likely to have been particularly beneficial for the development of students' knowledge-based arguments. As explained in Nussbaum and Sinatra (2003), students' deeper engagement and potential cognitive conflicts during a debate can rearrange their conceptual understanding of issues and expand their learning in a certain topic area (see also Dawes, 2004; Jafari & Meisert, 2019; Mercier & Sperber, 2011). Last but not least, in the particular context of animal testing, students seem to access fragmented knowledge (Dias & Guedes, 2018). This fragmentation might hinder them in making an informed judgment. The implemented teaching unit within this study might have helped fill these gaps.

6.7. Limitations, implications, and further research

One of the main limitations of this study is that we did not explicitly measure students' content knowledge to determine their issue familiarity. Instead, we decided to use the quantitative development of proposed arguments as evidence for a greater familiarity due to participation in the teaching unit. This approach was mainly chosen due to the limited testing time. Additionally, we assumed that administering content knowledge tests from particular disciplines (e.g., science knowledge) would not adequately capture the multifaceted nature of this issue (knowledge needed from diverse disciplines, e.g., science, ethics, economics). However, as Baytelman et al. (2020) argue, assessing students' familiarity using concept maps can be a resourceful method to evaluate the internal organization of students' understanding. Using such a tool would have resulted in a more robust conclusion and is thus recommended in further studies.

Secondly, we are aware that developing a teaching unit is a highly selective endeavor. In a study by Evagorou and Osborne (2013), for example, different students perceived the same issue differently, which highlights that even carefully designed teaching instructions do not work the same for each individual. It thus seems essential to keep in mind that our results might have been differing dependent on the structure of the teaching unit. We tried to reduce this variability by using our previously developed catalog of criteria during the design process.

Despite the promising results of this study, an important question remains unanswered. Within this study, the effect of issue familiarity on students' argumentation has been documented in the specific context of animal testing. Animal testing has been argued to be a particularly effective issue. The question therefore arises as to whether this deepening effect, due to increased issue familiarity, would have been similar for other SSI issues (e.g., climate change). Further research should replicate and clarify the distinctive effect of issue familiarity on students' multi-perspectival argumentation across varying issues. Researching a variety of issues might also allow a classification by difficulty, which could offer teachers an opportunity to choose more or less challenging SSI according to students' capabilities.

A recent study by Simonneaux and Lipp (2017) inspired a further research suggestion. Their study explored school students' argumentation about farm animal welfare. During data analysis, the authors observed that students used knowledge-based arguments to react to an area of emotional discomfort. Since the topic of animal testing is strongly intertwined with ethical conflicts and emotional distress, the same strategy might have been displayed by students in this study. A further study that focuses on students' justification strategies to avoid emotional discomfort in the context of animal testing is suggested.

An implication of the present study targets the inclusion of SSI within the classroom setting. As previous studies in the field of science education and the results of this paper suggest, negotiating complex societal issues necessarily entails the inclusion of multidisciplinary perspectives. This diversity highlights the interdisciplinary dynamics of the classroom, emphasizing the potential of progressive teaching pedagogies such as co-teaching (Forbes & Billet, 2012). Animal testing can serve as a valuable issue to connect science (specifically, biology) and social science (e.g., economics and politics) teachers to enable holistic learning experiences. As argued in Christenson et al. (2014), "explicitly making students (regardless of their discipline background) connect interdisciplinary resources to their SSI learning in school will likely enhance the students' skills to develop good-quality argumentation when discussing SSI" (p. 596). The SEE-SEP model can serve as a framework for teaching design purposes in this respect.

Being a scientific literate individual includes cultivating abilities that are necessary to negotiate pressing issues of the 21st century. Socioscientific argumentation, the ability to unravel the complexity of SSI through diverse arguments, is one of these necessary skills. The results of this study support and extend existing evidence that students are capable of discussing current SSI using multiple perspectives.

6.8. References

Agell, L., Soria, V., & Carrió, M. (2014). Using role play to debate animal testing. *Journal of Biological Education, 49*(3), 309–321.

Albe, V. (2008a). When scientific knowledge, daily life experience, epistemological and social considerations intersect: Students' argumentation in group discussions on a socio-scientific issue. *Research in Science Education, 38*(1), 67–90.

Albe, V. (2008b). Students' positions and considerations of scientific evidence about a controversial socioscientific issue. *Science & Education, 17*(8-9), 805–827.

Amiot, C., Bastian, B., & Martens, P. (2016). People and companion animals: It takes two to tango. *BioScience, 66*(7), 552–560.

Basel, N., Harms, U., Prechtl, H., Weiß, T., & Rothgangel, M. (2014). Students' arguments on the science and religion issue: The example of evolutionary theory and Genesis. *Journal of Biological Education, 48*(4), 179–187.

Baytelman, A., Iordanou, K., & Constantinou, C. (2020). Epistemic beliefs and prior knowledge as predictors of the construction of different types of arguments on socioscientific issues. *Journal of Research in Science Teaching*, online first retrieved from: https://onlinelibrary.wiley.com/doi/full/10.1002/tea.21627

Birdsall, S., & France, B. (2011). Attitudes towards using animals in research and teaching: Opinions from a selected group of female secondary school students. *Kotuitui: New Zealand Journal of Social Sciences Online, 6*(1-2), 15–25.

Cavagnetto, A. R. (2010). Argument to foster scientific literacy. *Review of Educational Research, 80*(3), 336–371.

Chang, S.-N., & Chiu, M.-H. (2008). Lakatos' scientific research programmes as a framework for analysing informal argumentation about socio-scientific issues. *International Journal of Science Education, 30*(13), 1753–1773.

Chang Rundgren, S.-N., & Rundgren, C. (2010). SEE-SEP: From a separate to a holistic view of socioscientific issues. *Asia-Parcific Forum on Science Learning and Teaching, 11*(1), 1–24.

Chinn, C. (2006). Learning to Argue. In A. M. O'Donell, C. E. Hmelo-Silver, & G. Erkens (Eds.), *Collaborative Learning, Reasoning and Technology* (pp. 355–383). Mahwah, New Jersey: Lawrence Erlbaum.

Christenson, N., Chang Rundgren, S.-N., & Höglund, H.-O. (2012). Using the SEE-SEP Model to analyze upper secondary students' use of supporting reasons in arguing socioscientific issues. *Journal of Science Education and Technology, 21*(3), 342–352.

Christenson, N., Chang Rundgren, S.-N., & Zeidler, D. L. (2014). The relationship of discipline background to upper secondary students' argumentation on socioscientific issues. *Research in Science Education, 44*(4), 581–601.

Colucci-Gray, L., Burnard, P., Gray, D., & Cooke, C. (2019). A critical review of STEAM (science, technology, engineering, arts, and mathematics). In P. Thomson (Ed.), *Oxford Research Encyclopedia of Education* (pp. 1-26). Oxford: Oxford University Press.

Dawes, L. (2004). Talk and learning in classroom science. *International Journal of Science Education, 26*(6), 677–695.

Dawson, V., & Carson, K. (2018). Introducing argumentation about climate change: Socioscientific issues in a disadvantaged school. *Research in Science Education, 38*(1), 67–88.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582–601.

Dias, T. M., & Guedes, P. G. (2018). Student knowledge about the use of animals in scientific research. *Revista Bioética, 26*(2), 235–244.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 83*(3), 287–312.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, *88*(6), 915–933.

Evagorou, M., Jimenez-Aleixandre, M. P., & Osborne, J. (2012). 'Should we kill the grey squirrels?' – A study exploring students' justifications and decision-making. *International Journal of Science Education, 34*(3), 401–428.

Evagorou, M., & Osborne, J. (2013). Exploring young students' collaborative argumentation within a socioscientific issue. *Journal of Research in Science Teaching, 50*(2), 209–237.

Faize, F. A., Husain, W., & Nisar, F. (2018). A critical review of scientific argumentation in science education. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(1), 475–483.

Fischer, F., & Kollar, I., Ufer, S., Sodian, B, Hussmann, H., Pekrun, R., … & Eberle, J. (2014). Scientific reasoning and argumentation: Advancing an interdisciplinary research agenda in education. *Frontline Learning Research*, *5*(2014), 28–45.

Forbes, L., & Billet, S. (2012). Successful co-teaching in the science classroom. *Science Scope, 36*(1), 61–64.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404–423.

Ford, M. J. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. *Cognition and Instruction, 30*(3), 207–245.

France, B., & Birdsall, S. (2015). Secondary students' attitudes to animal research: Examining the potential of a resource to communicate the scientist's perspective. *European Journal of Science and Mathematics Education, 3*(3), 233–249.

Grace, M. (2009). Developing high quality decision-making discussions about biological conservation in a normal classroom setting. *International Journal of Science Education, 31*(4), 551–570.

Grooms, J., Sampson, V., & Enderle, P. (2018). How concept familiarity and experience with scientific argumentation are related to the way groups participate in an episode of argumentation. *Journal of Research in Science Teaching*, *55*(9), 1264–1286.

Gruber, F. P., & Hartung, T. (2004). Alternatives to animal experimentation in basic research. *Alternatives to Animal Experimentation*, *21*(1), 3–31.

Haro, A., Noroozi, O., Biemans, H., & Mulder, M. (2020). Students' argumentation knowledge, behavior and attitude and their relationships with domain-specific knowledge acquisition. *Journal of Constructivist Psychology*, online first retrieved from: https://www.tandfonline.com/doi/full/10.1080/10720537.2020.1734995

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127.

Hoffmann, M. H. G. (2016). Reflective argumentation: A cognitive function of arguing. *Argumentation*, *30*(4), 365–397.

Hoffmann, M. H. G. (2018). The elusive notion of “argument quality”. *Argumentation, 32*(2), 213–240.

Holbrook, J., & Rannikmae, M. (2009). The meaning of scientific literacy. International *Journal of Environmental & Science Education, 4*(3), 275–288.

Holstermann, N., Grube, D., & Bögeholz, S. (2009). The influence of emotion on students’ performance in dissection exercises. *Journal of Biological Education, 43*(4), 164–168.

Jafari, M., & Meisert, A. (2019). Activating students’ argumentative resources on socioscientific issues by indirectly instructed reasoning and negotiation processes. *Research in Science Education*, Retrieved from: https://link.springer.com/article/10.1007/s11165-019-09869-x#citeas

Jiménez-Aleixandre, M. P., & Erduran, S. (2008). *Argumentation in science education: An overview.* In S. Erduran & M. Jiminez-Aleixandre (Eds.), Argumentation in Science Education: Perspectives from Classroom-based Research (pp. 3–27). Dordrecht: Springer.

Kahn, S., & Zeidler, D. (2017). A case for the use of conceptual analysis in science education research. *Journal of Research in Science Teaching, 54*(4), 538-551.

Kalvaitis, D., & Monhardt, R. (2015). Children voice biophilia; the phenomenology of being in love with nature. *Journal of Sustainability Education*, Vol. 9, retrieved from: http://www.susted.com/wordpress/content/children-voice-biophilia-the-phenomenology-of-being-in-love-with-nature_2015_03/.

Ke, L., Sadler, T., Zangori, L., & Friedrichsen, P. (2020). Students’ perceptions of socio-scientific issue-based learning and their appropriation of epistemic tools for system thinking. *International Journal for Science Education*, online first retrieved from: https://www.tandfonline.com/doi/full/10.1080/09500693.2020.1759843

KMK [Kultusministerkonferenz] (2004). *Bildungsstandards im Fach Biologie für den Mittleren Schulabschluss [Education Standards for Secondary School Biology]*. Retrieved from: https://www.kmk.org/fileadmin/Dateien/veroeffentlichungen_beschluesse/2004/2004_12_16-Bildungsstandards-Biologie.pdf.

Kolsø, S. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85*(3), 291–310.

Kolstø, S. D. (2006). Patterns in students’ argumentation confronted with a risk-focused socio-scientific issue. *International Journal of Science Education, 28*(14), 1689–1716.

Kuhn, D. (2018). A role for reasoning in a dialogic approach to critical thinking. *Topoi, 37*(1), 121–128.

Kuhn, D., & Udell, W. (2003). The development of argument skills. *Child Development, 74*(5), 1245-1260.

Kutnick, P., & Roger, C. (1994). *Groups in School*. London: Cassell.

Lee, H., & Abd-El-Khalick, A., & Choi, K. (2006). Korean science teachers’ perceptions of the introduction of socio-scientific issues into the science curriculum. Canadian *Journal of Science, Mathematics and Technology Education, 6*(2), 97–117.

Lee, Y. C. (2007). Developing decision-making skills for socio-scientific issues. *Journal of Biological Education, 41*(4), 170–177.

Lewis, J., & Leach, J. (2006). Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education, 28*(11), 1267–1287.

Lindahl, M., Folkessson, A., & Zeidler, D. (2019). Students' recognition of educational demands in the context of a socioscientific issues curriculum. *Journal of Research in Science Teaching, 56*(9), 1155-1182.

Marks, R., & Eilks, I. (2009). Promoting scientific literacy using a sociocritical and problem-oriented approach to chemistry teaching: Concept, examples, experiences. *International Journal of Environmental and Science Education, 4*(3), 231–245.

Means, M., & Voss, J. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction, 14*(2), 139–178.

Meigs, L., Smirnova, L., Rovida, C., Leist, M., & Hartung, T. (2018). Animal testing and its alternatives – the most important omics is economics. *Alternatives to Animal Experimentation, 35*(3), 275–305.

Mercier, H., Boudry, M., Paglieri, F., & Trouche, E. (2017). Natural-born arguers: Teaching how to make the best of our reasoning abilities. *Educational Psychologist, 52*(1), 1–16.

Mercier, H., & Sperber, D. (2011). Why do humans reason? Arguments for an argumentative theory. *The Behavioral and Brain Sciences, 34*(2), 57–111.

Monteiro, S., Sherbino, J., Sibbald, M., & Norman, G. (2020). Critical thinking, biases and dual processing: The enduring myth of generalisable skills. *Medical Education, 54*(1), 66–73.

NGSS [Next Generation Science Standards] (2013). *Next Generation Science Standards: For States, by States*. Washington, DC: The National Academies Press.

Nielsen, J. A. (2011). Science in discussion: An analysis of the use of science content in socioscientific discussions. *Science Education, 93*(3), 428–456.

Nielsen, J. A. (2013). Dialectical features of students' argumentation: A critical review of argumentation studies in science education. *Research in Science Education, 43*(1), 371–393.

NRC [National Research Council] (2012). *A Framework for K-12 Science Education: Practices, crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Nussbaum, E. M. (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist, 46*(2), 84–106.

Nussbaum, E. M., & Schraw, G. (2007). Promoting argument-counterargument integration in students' writing. *The Journal of Experimental Education, 76*(1), 59–92.

Nussbaum, E. M., & Sinatra, G. M. (2003). Argument and conceptual engagement. *Contemporary Educational Psychology, 28*(3), 384–395.

Ogan-Bekiroglu, F., & Eskin, H. (12). Examination of the relationship between engagement in scientific argumentation and conceptual knowledge. *International Journal of Science and Mathematics Education, 10*(1), 1415–1443.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020.

Osborne, J., Henderson, J. B., MacPherson, A., Szu, E., Wild, A., & Yao, S. (2016). The development and validation of a learning progression for argumentation in science. *Journal of Research in Science Teaching, 53*(6), 821–846.

Osborne, J., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education, 95*(4), 627–638.

Palm, J., & Keller, F. (2017). Im Versuchstierlabor: Forschen mit Leiden(-schaft). In: J. Palm & F. Keller (Eds.), *Ethik im Fokus: Tierethik [Focusing on ethics: Animal ethics]* (pp.55-61). Bamberg: Buchner Verlag.

Pedersen, J., & Totten, S. (2001). Beliefs of science teachers toward the teaching of science/technology/social issues: Are we addressing national standards? *Bulletin of Science, Technology & Society, 21*(5), 376–393.

Perkins, D., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher*, *18*(1), 16–25.

Polo, C., Lund, K., Plantin, C., & Niccolai, G. P. (2016). Group emotions: The social and cognitive functions of emotions. *International Journal of Computer-Supported Collaborative Learning, 11*(2), 1–39.

Presley, M. L., Sickel, A. J., Muslu, N., Merle-Johnson, D., Witzig, S. B., Izci, K., & Sadler, T. D. (2013). A framework for socio-scientific issues based education. *Science Education*, *22*(1), 26–32.

Ratcliffe, M. (1997). Pupil decision-making about socio-scientific issues within the science curriculum. *International Journal of Science Education, 19*(2), 167–182.

Reiss, M. J. (2017). A framework within which to determine how we should use animals in science education. In M. P. Mueller, D. J. Tippins & A. J. Stewart (Eds.), *Animals and Science Education – Ethics, Curriculum and Pedagogy* (pp. 243–259). Dordrecht: Springer.

Roberts, D. (2007). Scientific literacy/science literacy. In S. Abell & N. Lederman (Eds.), *Handbook of Research in Science Education* (pp. 729–780). Mahwah: Lawrence Erlbaum Associates.

Roberts, D. & Bybee, R. (2014). Scientific literacy, science literacy, and science education. In N. Lederman & S. Abell (Eds.) *Handbook of Research in Science Education Vol II* (pp. 697-726). New York, NY: Routledge.

Romine, W., Sadler, T., & Kinslow, A. (2017). Assessment of scientific literacy: Development and validation of the quantitative assessment of socio-scientific reasoning (QuASSR). *Journal of Research in Science Teaching, 54*(2), 274–295.

Sadler, T. (2011). *Socio-scientific Issues in the Classroom: Teaching, Learning and Research*. Dordrecht: Springer.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513–536.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*(4), 371–391.

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education, 28*(12), 1463–1488.

Sadler, T. D., Foulk, J. A., & Friedrichsen, P. J. (2017). Evolution of a model for socio-scientific issue teaching and learning. *International Journal of Education in Mathematics, Science and Technology, 5*(1), 75–87.

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education, 88*(1), 4–27.

Sadler, T. D., & Zeidler, D. L. (2005a). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching, 42*(1), 112–138.

Sadler, T. D., & Zeidler, D. L. (2005b). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education, 89*(1), 71–93.

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching, 46*(8), 909–921.

Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, *92*(3), 447–472.

Sampson, V., & Clark, D. B. (2011). A comparison of the collaborative scientific argumentation practices of two high and two low performing groups. *Research in Science Education, 41*(1), 63–97.

Schmidt, H., Rothgangel, M., & Grube, D. (2015). Prior knowledge in recalling arguments in bioethical dilemmas. *Frontiers in Psychology, 6*(1292), 1-10.

Schmidt, H., Rothgangel, M., & Grube, D. (2017). Does prior domain-specific content knowledge influence students' recall of arguments surrounding interdisciplinary topics? *Journal of Adolescence, 61*(2017), 96–106.

Schwarz, B., Neuman, Y., Gil, J., & Ilya, M. (2003). Construction of collective and individual knowledge in argumentative activity. *Journal of the Learning Sciences, 12*(2), 219–256.

Schwarz, B., & Asterhan, C. (2010). Argumentation and reasoning. In K. Littleton & C. Wood, & J. Kleine Staarman (Eds.), *International Handbook of Psychology in Education* (pp. 137–176). Bingley: Emerald Group.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2-3), 235–260.

Simonneaux, L., & Lipp, A. (2017). Emotions, values and knowledge in students' argumentation about farm animal welfare. ESERA 2017, Dublin, Ireland.

Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education, 49*(1), 1–34.

Topcu, M. S., Sadler, T. D., & Yilmaz-Tuzun, O. (2010). Preservice science teachers' informal reasoning about socioscientific issues: The influence of issue context. *International Journal of Science Education, 32*(18), 2475–2495.

Toulmin, S. (1958). *The uses of arguments*. Cambridge: Cambridge University Press.

Udell, W. (2007). Enhancing adolescent girls' argument skills in reasoning about personal and non-personal decisions. *Cognitive Development, 22*(3), 341–352.

Von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101–131.

Walker, K., & Zeidler, D. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International Journal of Science Education, 29*(11), 1387–1410.

Walton, D. (1990). What is reasoning? What is an argument? *The Journal of Philosophy, 87*(8), 399–419.

Wu, Y.-T., & Tsai, C.-C. (2007). High school students' informal reasoning on a socio-scientific issue: Qualitative and quantitative analyses. *International Journal of Science Education, 29*(9), 1163–1187.

Yager, R. E. (1993). Science-technology-society as reform. *School Science and Mathematics*, *93*(3), 145–151.

Zeidler, D. (2014). Socioscientific issues as a curriculum emphasis: Theory, research and practice. In N. Lederman & S. Abell (Eds.) *Handbook of Research in Science Education Vol II* (pp. 697–726). New York, NY: Routledge.

Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research, 1*(11), 1–9.

Zeidler, D. L., & Sadler, T. (2007). The role of moral reasoning in argumentation: Conscience, character, and care. In S. Erduran & M. Jiménez-Aleixandre (Eds.), *Argumentation in Science Education* (pp. 201–216). Dordrecht: Springer.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62.

7. SUMMARIES OF THE CONDUCTED STUDIES

Three studies were carried out as part of this dissertation. Each of the studies will be briefly summarized in the following with emphasis on their purpose, procedure, and main results. A comprehensive discussion of the results, as well as how these new insights can be integrated within the greater body of literature, will take place in Chapter 8.

7.1. Study 1 (Chapter 4)

The ability to make informed decisions is essential for the promotion of a more sustainable future. To understand and address sustainability-related issues, to negotiate possible solutions, and to enact change requires students to comprehend and apply scientific ideas. Science education therefore plays a critical role in this endeavor. However, formal regulations *within* the classroom, such as short instruction time and discipline-driven boundaries, might impede the thorough promotion of students' decision-making. Study 1, conclusively, purposed to identify and analyze empirical studies in the field of science education that discuss the intersection of (1) students' socioscientific decision-making in (2) sustainability-related (3) extracurricular activities. Data were collected from three databases using individual syntaxes. To assure a systematic procedure, the identification and selection of relevant articles was guided by the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green, 2011) and the preferred reporting of items for systematic reviews and meta-analyses guidelines (PRISMA; Moher et al., 2009; Moher et al., 2015). After the selection process, 19 out of 356 articles were determined sharing the common intersection of all three components. Despite this overlap, each of the articles was found to prioritize one of the three components which resulted in the establishment of three groups.

Group 1: Most of the articles (n = 14) focus on the first component, i.e., socioscientific decision-making. In this group, socioscientific decision-making is treated as a measurable competence which can be assessed in terms of its development, quality, and inherent structure. Studies within this group understand socioscientific decision-making as a rather individual, cognitively demanding, and systematic process.

Group 2: Some of the articles (n = 3) focus on the educational embodiment within which decision-making occurred. In this group, the characteristics of the educational setting initiated students' engagement with socioscientific decision-making. All of these articles report on how students were asked to approach *local* problems to meaningfully involve them in the negotiation of community matters.

Group 3: The last group of studies (n = 2) pays predominant attention to sustainable development as a suitable issue for students to express their opinion and thoughts on real-world problems. Socioscientific decision-making, in this group, was understood as a tool aiming for students' empowerment.

Besides this classification of articles into three groups, two closing remarks are of central importance for this dissertation. First, the classification of articles disclosed evidence for two *different* notions of socioscientific decision-making. Whereas articles from the first group depict decision-making as a rational and mostly individual process, the latter two groups characterize students' decision-making in a more cooperative light highlighting its social embeddedness. Secondly, there has been no study which displayed an equal distribution of attention among all three components.

7.2. Study 2 (Chapter 5)

Based upon the findings from Study 1, Study 2 translated the identified gap (no equal distribution of attention among all three components) into an empirical research endeavor. The BUW, an extracurricular and project-oriented science competition that invites students to explore local, sustainability-related questions, constitutes the setting for Study 2. The competition's inquiry-based and self-regulated learning approach combined with its thematic orientation (sustainable development) is assumed to involve participants in socioscientific decision-making. The purpose of Study 2 was to investigate the effectiveness of the BUW to foster students' socioscientific decision-making. A paper-and-pencil questionnaire by Eggert and Bögeholz (2010), as well as retrospective interviews, were conducted in two successive sub-studies. In order to provide assessment-related insight, both of the applied instruments were evaluated in light of the "assessment triangle" (National Research Council, 2001), a commonly employed framework within science education.

Sub-study 1: The first sub-study assessed students' socioscientific decision-making in its selectional phase. To mimic the competition's distribution of participants, 196 students from four federal states (Northern, Eastern, and Southern Germany) and three different school types (grammar school, comprehensive school, and pre-vocational school) completed a 45-minute paper-and-pencil questionnaire by Eggert and Bögeholz (2010) in a repeated measures design. From these students, 81 were also participants of the BUW 2017/2018 and hence belonged to the treatment group. The remaining students (n = 115) served as a control group and took part in the regular school life (no participation in the BUW). The analysis of data revealed no significant changes from the pretest to the posttest in either group with regard to students' development of socioscientific decision-making in its *selectional phase*. However, a statistically significant interaction between time and group indicated that BUW-participants showed an increased use of arguments after the competition and compared to the control group in order to answer the questionnaire tasks.

Sub-study 2: As part of the second sub-study, 30-minute retrospective interviews were conducted with 10 participants of two different competition groups. The 26 problem-oriented interview questions aimed to extend the insights gained in sub-study 1 by focusing on students' decision-making experiences as part of their competition participation. The analysis of the interview data showed evidence for students' decision-making in its pre-selectional *and* selectional phase; however, a predominance of decision-making in its pre-selectional phase was observed. The interview data also revealed evidence for both notions of socioscientific decision-making (see Study 1).

Overall, the results of both sub-studies support the conceptualization of decision-making as a multi-phased process that can occur with reference to two different notions. This consideration is strengthened by the instruments' theoretical evaluation which indicated that socioscientific decision-making can be recorded on two different levels: On a structural level (selectional phase, use of strategies, sub-study 1) and on a more explorative level (pre-selectional phase, content-oriented, sub-study 2).

7.3. Study 3 (Chapter 6)

In contrast to the first two studies, which both payed attention to the potentials of extracurricular activities, Study 3 focused on the promotion of socioscientific decision-making *within* the regular classroom. Since regular lessons are subject to strict temporal limitations, suitable SSI should engage students in socioscientific discourse rather easily. Animal testing seems to address this demand.

As part of Study 3, students' multi-perspectival argumentation was investigated. The term 'multi-perspectival' refers to arguments from (a) multiple disciplines, meaning that animal testing derives from different disciplines, such as biology and ethics, which must be considered when holistically negotiating this issue. It also refers to arguments from (b) multiple dimensions, implying that negotiating this SSI requires evidence-based considerations (descriptive dimension) as well as ethical reflections (normative dimension). The purpose of Study 3 was (1) to examine whether animal testing engages students in multi-perspectival argumentation *without* additional issue familiarity and (2) to clarify the relationship between *additional* issue familiarity and students' multi-perspectival argumentation. A total of 164 secondary school students from Northern Germany participated in this study which followed a quasi-experimental repeated measures design. One hundred six of these students took also part in a teaching unit about animal testing to familiarize themselves with the issue (treatment group). Two open-ended items were employed to ascertain students' views about animal testing. The SEE-SEP model by Chang Rundgren and Rundgren (2010) served as an analysis scheme to investigate students' answers in terms of multi-perspectival argumentation.

The results of Study 3 demonstrate that students were able to utilize a reasonable number of multidisciplinary and multidimensional arguments even *before* further familiarizing themselves with the issue. The detailed analysis of students' argumentation in the pre- and posttest further indicates that an increase in issue familiarity did not enhance the *diversity* of multidisciplinary and multidimensional arguments presented by students; however, the *depth* of already predominant disciplines and dimensions was manifested.

8. DISCUSSION AND PERSPECTIVES

Three studies were conducted as part of this dissertation to extend the current knowledge about students' socioscientific decision-making in formal and non-formal learning opportunities. The studies' results are discussed in-depth as part of the respective research articles and the manuscript (Chapter 4-6). The following section aspires to relate these results to the four challenges that have been previously identified. This overall discussion further provides practical and research-oriented implications (see Chapter 8.2 and Chapter 8.4) and highlights some of this work's limitations (see Chapter 8.5). The structure of this chapter is illustrated in Figure 8.1.

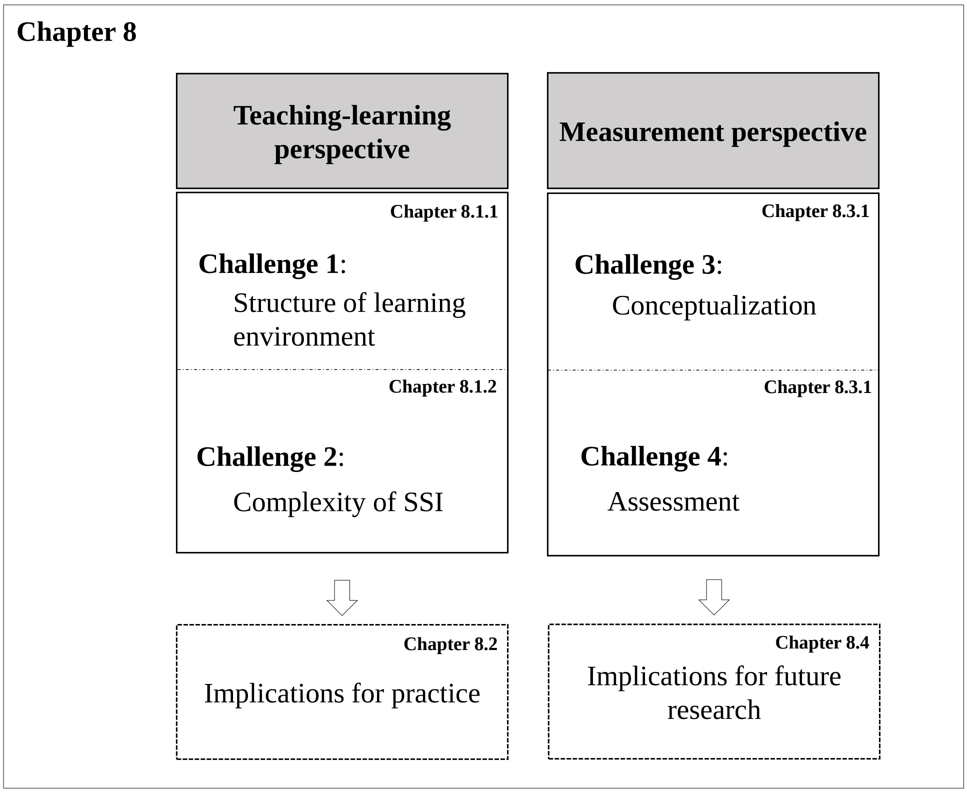

Figure 8.1: Structure of the overall discussion.

8.1. Teaching-learning perspective

As part of the teaching-learning perspective, two challenges have been identified with respect to the promotion of students' socioscientific decision-making: The structure of the learning environment (Challenge 1) and the inherent complexity of SSI (Challenge 2).

8.1.1. The structure of the learning environment

In the previous chapters, the structural and temporal limitations *within* the regular science classroom have been outlined as severe obstacles for students' engagement with socioscientific decision-making (see also Bell, 2009). Due to these formal circumstances, the socioscientific discourse often seems to be stuck at an ‘academic level’ neglecting the transfer of these considerations into real-world action (Zeidler, 2014).

Results of Study 1 and Study 2 underline the potentials of extracurricular learning activities in this respect. Study 1 identified a lack of research that pays equal attention to students’ (1) socioscientific decision-making in (2) sustainability-related (3) extracurricular activities. Study 2 addressed this gap in an empirical manner by investigating an extracurricular and sustainability-related learning opportunity (BUW) in its effectiveness to promote participants’ socioscientific decision-making. A common theme that emerged from both studies (Study 1 and Study 2) embodies students’ empowerment.

Students’ empowerment as capable social actors: The results from the systematic literature review (Study 1) combined with the empirical evidence that was found in Study 2 indicate that students, in suitable learning environments, are able to contribute to the resolving of complex, sustainability-related issues. This is not a trivial finding: Recent studies by Tidemand and Nielsen (2017) as well as Ekborg and colleagues (2013) report that teachers tend to underestimate students’ capabilities to meaningfully engage in the negotiation of SSI. In their in-depth study about science teachers’ experiences with implementing SSI, Ekborg et al. (2013) documented a number of concerns mentioned by teachers. These concerns encompassed that students might find it too difficult to work within student-centred and discursive formats that often lack clear and detailed instruction. As an example, some teachers expressed their worries that students might struggle to independently find and evaluate information (i.e., pre-selectional phase of socioscientific decision-making). This assumption, in particular, was contradicted by the findings of the present dissertation. The results of Study 2 present evidence that participants of the BUW frequently engaged in the selection and evaluation of information (pre-selectional phase). Furthermore, the positive experiences connected to students’ independent working were a common theme within the interview data.

As shown in the results of the literature review (Study 1), articles that primarily focused on the educational embodiment (i.e., characteristics of the learning environment) framed the issues’ communal embeddedness as particularly valuable for students’ development of socioscientific decision-making. Similarly, the learning environment of Study 2 (BUW) required participants to identify and negotiate a *local* SSI. As noted in Capkinoglu, Yilmaz, and Leblebicioglu (2020), many of the SSI that are used for teaching and research purposes consider a global perspective (e.g., stem cell research, climate change, nuclear power usage). Results of our studies (Study 1 and Study 2) suggest that it might be the apparently often neglected local connectedness that enables students to add an active dimension to their decision-making. Moreover, it might be this interconnectedness with their social environment that shifts the discussion from the previously criticized ‘academic level’ to a participatory level which mobilizes socio-political action (Zeidler et al., 2005; Zeidler, 2014).

Students' empowerment as future scientists: In addition to students' empowerment as capable social actors (see also Prout, 2001, 2002), results of Study 2 also suggest that the BUW provided students with authentic science experiences.
Students' science-related discourse, according to Jiménez-Aleixandre, Rodríguez, and Duschl (2000), can be distinguished into two types: 'Doing school' and 'doing science'. Whereas 'doing school' refers to students' understanding of how to behave and what to expect within the science classroom, 'doing science' includes students' abilities to meaningfully participate in scientific practice and dialogue. The analysis of the interview data from Study 2 affirmed that, while participating in the competition, students engaged in 'doing science'. Students' scientific inquiry, i.e., to independently research their project-related questions, was thus a central experience during the competition. This insight unfolds two remarks concerning suitable learning environments for students' socioscientific decision-making. First, researching a problem in a self-regulated manner emphasizes students' autonomy within the learning process and might further require them to make sensible decisions (Stefanou, Perencevich, DiCintio, & Turner, 2004). Secondly, the opportunity for scientific inquiry as part of their BUW-project development might have functioned as catalyst for students' epistemic agency. Epistemic agency, in this case, means that participants were encouraged to scientifically investigate a question that was meaningful to them. Inquiring about this question resulted in a situation that allowed them "to make changes in larger societal structures (i.e., to see science as meaningful for their lives and their communities)" (Miller, Manz, Russ, Stroupe, & Berland, 2018, p. 1066). Tapping students' epistemic agency seems necessary for the development of socioscientific decision-making because their epistemological understanding influences, for example, "the way in which students select and evaluate evidence" (Zeidler et al., 2005, p. 362).

Overall, Study 1 and Study 2 provide evidence that extracurricular learning environments, which offer similar conditions to the BUW, can enable students to thoroughly engage in socioscientific decision-making. Such an engagement can touch upon both their empowerment as informed social actors (Vision II scientific literacy) and as future scientists (Vision I scientific literacy).

8.1.2. The complexity of SSI

A limited understanding of the inherent complexity of SSI can obstruct informed decision-making and subsequent action (Yoon, 2011). Recognizing and unravelling this complexity is therefore a time-consuming but necessary aspect of the decision-making process. Yet, severe time constraints within the regular science classroom are an often quoted challenge in this respect (Sadler et al., 2006). The results of Study 3 portray animal testing as an effective issue for the regular science classroom that allows students to explore the inherent complexity even without prior issue familiarity. In Study 3, students' use of multi-perspectival arguments served as an indicator for a deepened engagement and no oversimplification of the issue (Sadler, Barab et al., 2007).

The interview data from Study 2 present evidence that BUW-participants adequately addressed the complexity of their sustainability-related project issues. One interview category, for example, summarized students' awareness and concern about the intra- and intergenerational responsibility, which could indicate students' involvement with a normative dimension (see also Langhelle, 1999). Another category that emerged from the analysis of the interview data described students' change in perspective (namely consequences for humans *and* animals). There was further evidence that students critically questioned the origin of information which consequently required them to take different interests into account. These multi-perspectival considerations have been acknowledged as important aspects with regard to the complexity of SSI (see Chapter 2.2).
Sustainability-related issues are frequently chosen SSI within science education (see also Bögeholz et al., 2014). However, recognizing the fundamental complexity inherent to sustainability-related issues can be a severe difficulty for students (e.g., Liu et al., 2011; Wu & Tsai, 2007). One possible explanation why BUW-participants adequately addressed the complexity of their project-related SSI might be, again, the inquiry-based learning environment. As part of their competition experience, students usually identify a research question and independently conduct the gathering and analysis of respective data. A strong interdependence between students' realistic conceptions about how, for example, scientific procedures are done or scientific knowledge is produced (i.e., nature of science) and the depth of their socioscientific discourse has been reported in several studies (e.g., Bell, Matkins, & Gansneder, 2011; Lederman, Antink, & Bartos, 2014; Sadler, Chambers, & Zeidler, 2007).

In both empirical studies (Study 2 and Study 3), students dealt adequately with the complexity of SSI as part of their socioscientific decision-making. Yet, many SSI require an *in-depth* consideration to understand the "dynamic interactions within SSI which preclude simple, linear solutions" (Sadler, Barab et al., 2007, p. 375). The question remains how students can be assisted in this endeavor. Results from Study 3 indicate that an increased issue familiarity does not enhance the diversity of students' perspectives. Conversely, more instructional guidance seems needed. This will be further addressed in the next section.

8.2. Implications for practice

Results of Study 3 suggest that increased issue familiarity enhances the *depth* of previously manifested perspectives in students' socioscientific argumentation. Yet, it is the *diversity* of perspectives that is considered to improve the quality of students' socioscientific decision-making (Chang Rundgren & Rundgren, 2010; Lee et al., 2019; Lindahl et al., 2019; Wu & Tsai, 2007). Conclusively, more instructional guidance seems necessary to assist students in unravelling the complexity of SSI.

In a recently published article by Ke, Sadler, Zangori, and Friedrichsen (2020), the 'Star Chart' was introduced. This tool, in shape of a five-pointed star, aims to help students recognizing the complex nature of SSI and to scaffold their view. Each of the five corner vertices is labelled with one of these disciplines: Science, economics, politics, religion, and ethics. The word 'issue' is printed in the middle. While this tool provides first entry points for students to explore the different disciplines that can be interwoven into an SSI, it seems to neglect the inclusion of multidimensional aspects (descriptive and normative) and lacks more in-depth instructional guidance. Drawing upon the results from Study 3, which reveal that students make use of multidisciplinary *and* multidimensional aspects during their argumentation, the 'Snowflake Chart' (see Figure 8.2) represents a further development of the 'Star Chart' that explicitly considers these points. The 'Snowflake Chart' has two sides:

Side A: Similar to the 'Star Chart', the one side of the 'Snowflake Chart' focuses on the six disciplines that have been identified by the SEE-SEP model as commonly referenced disciplines during the negotiation of SSI: Sociology/Culture, environment, economy, science, ethics/morality, and politics (Chang Rundgren & Rundgren, 2010). In addition, two explicit questions aim to guide students' negotiation. Actively slipping into the viewpoints of others, for example, can help to explore the different sides of a problem (Howes & Cruz, 2009).

Side B: The other side of the 'Snowflake Chart' concentrates on the different dimensions that can be touched upon while dealing with SSI: Knowledge (descriptive dimension), experience, and value (normative dimension; according to the SEE-SEP model by Chang Rundgren & Rundgren, 2010). Three reflective questions guide students' further negotiation. To reflect upon the underlying value of an argument, for instance, can assist students in coming to an informed decision (Hößle & Alfs, 2014).

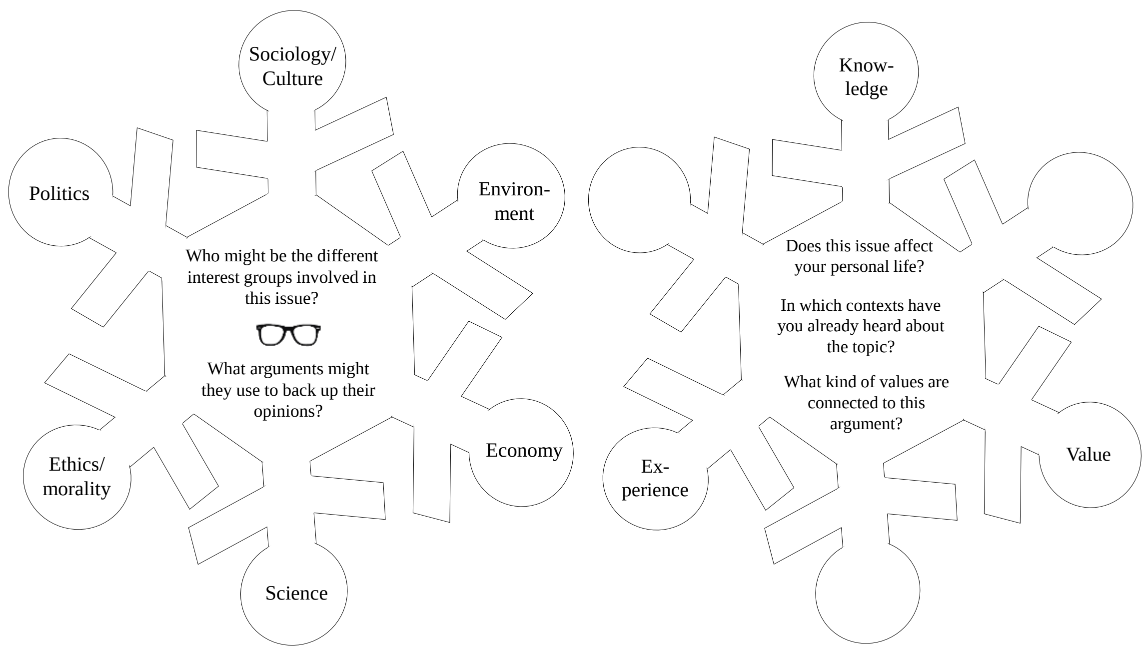

Figure 8.2: Prototype of the 'Snowflake Chart' printed on both sides (A and B), disciplines and dimensions adapted from the SEE-SEP model by Chang Rundgren & Rundgren (2010).

The empirical insights gained from Study 2 and Study 3 were also integrated into the development of teaching materials for the project "Expedition Erdreich - Wissenschaftsjahr 2020" [Expedition Soil - Science Year 2020]. The fundamental aim of these teaching materials was to combine soil-related scientific knowledge with underlying societal aspects to stimulate, amongst other things, students' socioscientific discourse. Whenever possible, the teaching material encouraged students to consider their local circumstances. This local connectedness has been outlined as valuable entry point for students' socioscientific decision-making and socio-political action (see Chapter 8.1.1). An exemplary work sheet can be found in the supplementary materials (see Chapter 11.3).

8.3. Measurement perspective

As part of the measurement perspective, two challenges have been identified with respect to socioscientific decision-making: The conceptualization (Challenge 3) and the assessment (Challenge 4). Due to their interconnectedness, both challenges will be discussed in an integrated section.

8.3.1. Conceptualization and assessment of socioscientific decision-making

One of the latest and most comprehensive endeavors to conceptualize socioscientific decision-making constitutes the review by Fang and colleagues (2019; see Chapter 2.2.1). Their theoretical framework involves three interconnected phases: Identifying a decision situation (pre-selectional phase; phase 1), selecting suitable strategies for decision-making (selectional phase; phase 2), and the reflection phase (post-selectional phase; phase 3). Despite the depth of their analysis, socioscientific decision-making is considered as a cognitive process that is primarily carried out on an individual level. A similar picture (multi-phased process on an individual level) illustrates the Göttinger model for socioscientific decision-making, which is one of the most prominent frameworks on a national level (Eggert & Bögeholz, 2006).

In Study 1, 19 articles have been systematically reviewed to examine socioscientific decision-making in extracurricular and sustainability-related learning activities. As part of the results, two different notions of socioscientific decision-making have been exposed: An individual and a more cooperative, socially embedded notion. While most of the studies that aimed to measure students' socioscientific decision-making *within* the classroom or within similarly structured settings payed attention to the individual notion, the cooperative notion was predominantly identified in studies that concerned students' general empowerment *in*- and *outside* the classroom. In Study 2, further empirical evidence for both notions has been found. This differentiation (i.e., individual or cooperative notion) might be helpful for future research endeavors to refine the reporting of outcomes concerning students' socioscientific decision-making. Furthermore, two different decision-making phases have been determined as being part of participants' competition experience: The pre-selectional phase and the selectional phase (Study 2). This evidence strengthens the assumption that socioscientific decision-making is a multi-phased process (see also Fang et al., 2019).

The way socioscientific decision-making is conceptualized plays an important role for both science education research and practice (Eggert & Bögeholz, 2010). On the one hand, teachers are responsible for developing suitable teaching interventions that involve students in socioscientific discourse. To anticipate and diagnose potential learning difficulties, it appears beneficial for teachers to understand and refer to the underlying construct (see also Kim, Anthony, & Blades, 2014). On the other hand, to evaluate the success of these learning interventions requires suitable assessment instruments.

The literature review conducted in Study 1 revealed that most of the articles (14 out of 19 articles) constructed socioscientific decision-making as a quantitatively measurable competence, which can be assessed to evaluate the effectiveness of a particular intervention. This majority indicates that the assessment of decision-making is a key concern in science education. With regard to the articles from Germany (4 out of 14 articles), this can be further associated with the integration of socioscientific decision-making as an independent competence area within the national educational standards for science education (see also KMK, 2005a, KMK, 2005b, KMK, 2005c).

Despite the broadly received support for including a more applied emphasis of scientific literacy (Vision II), there has equally been critical voices highlighting the insufficiency of appropriate assessment methods (Orpwood, 2001, 2007). Study 2 addressed this concern and theoretically evaluated two different instruments employing the “assessment triangle” (National Research Council, 2001). A closer examination showed that each instrument applied a different focus: While one instrument explored decision-making on a structural level (appropriate use of strategies), the other instrument investigated decision-making exploratively (content-oriented reasoning). These foci were further associated with different phases of socioscientific decision-making (pre-selectional and selectional phase). This methodological finding highlights the diverse strengths of different instruments and, moreover, emphasizes the need for clearly formulated research aims. In addition, as in the case of Study 2, the implementation of diverse instruments can result in a more holistic perspective on the development of students’ socioscientific decision-making (Kuckartz, 2014).

8.4. Implications for future research

This section will provide suggestions for further research concerning both the teaching-learning and the measurement perspective.

8.4.1. Teaching-learning perspective

Both of the empirical studies (Study 2 and Study 3) focus on students’ perspectives and struggles regarding the development of socioscientific decision-making. The quality of students’ learning experience, however, is greatly influenced by teachers and their instruction (Kunter et al., 2013; Mahler, Großschedl, & Harms, 2017). Future research should enlarge the studies conducted within this dissertation and concentrate on the difficulties experienced by teachers when (a) accompanying a group of students during participation in the BUW and (b) carrying out the teaching unit about animal testing. These studies could potentially uncover teachers' struggles which might further affect their practice and thus students' learning experiences. These insights would enable a more holistic understanding of the dynamics that regulate the development of students' socioscientific decision-making.

Drawing upon the findings from Study 3, further research is encouraged to examine the role of instructional guidance for students' multi-perspectival argumentation. An exemplary study could implement the same teaching unit (animal testing, see 6.4.2) for different treatment groups, whereas each treatment group uses different tools, such as the 'Snowflake Chart' or the 'Star Chart'. The respective results would allow more detailed statements about the effectiveness of the tools' features to assist students in unravelling the complexity of SSI.

Last but not least, an additional study that follows a comparable design to Study 3 (similar overall structure and comparable learning activities) but employs a sustainability-related issue as teaching content should be conducted. This could (a) clarify the suitability of animal testing as advantageous SSI for students' multi-perspectival argumentation and (b) investigate the effects of the previously outlined differences between both issues (Chapter 2.3) on students' socioscientific decision-making.

8.4.2. Measurement perspective

As part of their competition experience, students of the treatment group (Study 2) were required to examine a local SSI (pre-selectional phase), to develop possible solutions (selectional phase), and to put these solutions into practice (post-selectional phase). However, due to the conceptualization used within this dissertation, the post-selectional phase of students' socioscientific decision-making, i.e., the actual enactment of the decision, played a minor role. A further study is suggested that concentrates on the whole decision-making process for a greater insight into the conceptual interconnectedness of the different phases. The BUW seems to offer the optimal environment for such a research endeavor because it allows an in-depth insight into students' decision-making for all three phases of the decision-making process.

Furthermore, findings from Study 1 and Study 2 illustrate two different notions that seem relevant with respect to students' socioscientific decision-making experiences. A further research study should aim to follow a more systematic procedure to define characteristics of each notion. In a first and explorative step, appropriate methods might encompass qualitative techniques such as think-aloud protocols (individual notion) or focus groups (cooperative notions; see also Robson, 2011). This differentiation between both notions could assist other scholars to guide their selection of suitable assessment instruments.

8.5. Limitations of the conducted studies

Study design: Even though it would have been interesting to examine how BUW-participants enhance or adjust their decision-making from one year of participation to another, the limited time available for this dissertation project restricted the application of a longitudinal study design (Study 2). Therefore, this dissertation can only give limited insights into the development of students' socioscientific decision-making over one participation cycle. Research conducted over several participation cycles could, for example, investigate the role of previous experiences for students' decision-making in similar learning situations.

Sample and generalizability: The treatment group of Study 2 comprised 81 participants of an environmental science competition. Participants of science competitions might be viewed as a highly selective group of strongly motivated science students aiming to compete with peers (see also Petersen & Wulff, 2017). Findings from Study 2 are therefore limited in their generalization beyond the study sample and explicit setting. Yet, similar conclusions which highlight the potentials of local connectedness (e.g., Herman, Zeidler, & Newton, 2018), inquiry-based learning approaches (e.g., Bencze et al., 2012), and sustainable-related issues (e.g., Eggert & Bögeholz, 2010) for socioscientific decision-making have been previously reported in other studies. Students' experiences and the subsequent insights gained from Study 2 are valuable and can, with caution, inform practice in similar or different educational settings.

Data collection: A limitation of Study 3 refers to the teaching unit which was introduced to familiarize students of the treatment group with the issue of animal testing. The implementation of this teaching unit was mainly carried out by the author of this dissertation. This might have been an uncommon situation for the students who are used to being taught by their well-known science teacher. Conclusively, students might have behaved differently during the intervention. This could have influenced their performance during the assessment. On the other hand, the external implementation ensured a certain degree of comparability between classes because potential differences in the delivery (e.g., teaching style, assistance during activities) were eliminated.

Composition of studies: To gain a fuller understanding of students' socioscientific decision-making, this dissertation implemented three separate studies that investigated two different issues (sustainable development and animal testing), as well as two educational settings (extracurricular activities and classroom setting). To make any comparing conclusions about the suitability of each aspect, studies with a greater overlap (e.g., overlap of issue: animal testing as an issue for teaching within *and* outside the science classroom) would have been necessary. Due to these differences, this dissertation cannot make any comparing conclusions. However, it is essential to emphasize that the aim of this work was not to compare the issues under debate or the educational settings but to spotlight the unique potentials of each one.

9. CONCLUSION

In 2015, the OECD launched their project *The Future of Education and Skills: Education 2030* to define the cornerstones of contemporary education that prepares students “to adapt to, thrive in and even shape whatever the future holds” (OECD, 2019, p. 5). In a first phase, the OECD-project identified competencies that are necessary for today’s students to support individual and collective well-being. The second and currently running phase investigates how learning opportunities need to be designed for the promotion of these competencies (OECD, 2019). The present dissertation fits well into this two-phased procedure by advocating socioscientific decision-making as a necessary competence for today’s students and, secondly, by providing first insights into how to address four challenges connected to its promotion and assessment.

Three studies were carried out as part of this dissertation. Their results contribute to the current state of knowledge about students’ socioscientific decision-making and its development. These insights, building upon work that has been previously done by other scholars from the science education community, inform two general recommendations for contemporary science education:

> **Recommendation**: Contemporary science education should empower students to investigate, individually and/or collectively, science-related social questions that are meaningful to their lives. Extracurricular learning environments display additional learning opportunities that should be acknowledged as valuable entry points in this respect.
>
>> Being a scientifically literate individual entails cultivating abilities that are necessary for the dealing with pressing issues of the modern world. Socioscientific decision-making, students’ multi-perspectival considerations of science-related social issues (see also Lee & Grace, 2010; 2012), is one of these necessary competencies. Conclusively, contemporary science education should explicitly acknowledge, value, and promote students’ socioscientific decision-making (e.g., KMK, 2005a; NGSS, 2013; NRC, 2012).
>>
>> The three studies that were conducted as part of this dissertation displayed two different settings for the promotion of students’ socioscientific decision-making: The regular science classroom (Study 3) and extracurricular learning activities (Study 1 and Study 2). While both settings were able to address decision-making in its individual notion, the added value of extracurricular activities has been outlined in the potentials to also integrate its cooperative notion. Furthermore, the local embeddedness added an active dimension to students’ decision-making and endorsed socio-political action concerning issues that were of interest to them or their communities. This empowerment illustrates socioscientific decision-making as “a major element of being a citizen in a democratic society” (Tal, Kali, Magid, & Madhok, 2011, p. 12).

Recommendation: Contemporary science education should empower students and teachers to reach beyond their subject boundaries to address and resolve the complexity of SSI. In this respect, contemporary science education should support necessary structural changes and provide the needed resources to support interdisciplinary working among both students and teachers.

Resolving the inherent complexity of SSI is highlighted as a key challenge within this dissertation. A mere familiarization with the SSI has been shown as insufficient to enlarge students' multi-perspectival argumentation in this respect (Study 3). For more instructional guidance, the 'Snowflake Chart' has been developed (see Chapter 8.2).

Based on students' difficulties to engage with the complexity on an *in-depth* level, teachers should explicitly communicate the multi-perspectival aspects of SSI in their teaching. This interdisciplinary demand might require a stronger consideration of progressive teaching pedagogies such as co-teaching (see also Forbes & Billet, 2012) or structural changes that soften the boundaries between the different science subjects (i.e. biology, physics, and chemistry; see also You, 2017)

To anticipate which competencies will be important in a yet uncertain future is a highly difficult task (OECD, 2019). The results of this work support other scholars from the science education community who argue that socioscientific decision-making is one of these competencies. While there will never be an easy answer as to how contemporary science education should be framed, this dissertation adds a further piece to the question how it can promote the cultivation of scientifically literate individuals capable of facing science-related social issues nowadays and in the future.

10. REFERENCES[13]

Abbott, A. (2010). Basel declaration defends animal research: Dialogue with public is key to reducing opposition over the use of lab animals. *Nature*, *468*(7325), 742. https://doi.org/10.1038/468742a

Acar, O., Turkmen, L., & Roychoudhury, A. (2010). Student difficulties in socio-scientific argumentation and decision-making research findings: Crossing the borders of two research lines. *International Journal of Science Education*, *32*(9), 1191–1206. https://doi.org/10.1080/09500690902991805

Agell, L., Soria, V., & Carrió, M. (2014). Using role play to debate animal testing. *Journal of Biological Education*, *49*(3), 309–321. https://doi.org/10.1080/00219266.2014.943788

Aikenhead, G. S. (2006). *Science Education for Everyday Life: Evidence-based practice*. New York, NY: Teachers College.

Asterhan, C. S. C., & Schwarz, B. B. (2016). Argumentation for learning: Well-trodden paths and unexplored territories. *Educational Psychologist*, *51*(2), 164–187. https://doi.org/10.1080/00461520.2016.1155458

Bawa, K. S., & Seidler, R. (2009). *Dimensions of Sustainable Development: Encyclopedia of life support systems*. Oxford, UK: Eolss Publishers.

Bell, P. (2009). *Learning science in informal environments: People, places, and pursuits*. Washington D.C.: National Academies Press.

Bell, R. L., Matkins, J. J., & Gansneder, B. M. (2011). Impacts of contextual and explicit instruction on preservice elementary teachers' understandings of the nature of science. *Journal of Research in Science Teaching*, *48*(4), 414–436. https://doi.org/10.1002/tea.20402

Bencze, L., Pouliot, C., Pedretti, E., Simonneaux, L., Simonneaux, J., & Zeidler, D. (2020). SAQ, SSI and STSE education: Defending and extending “science-in-context”. *Cultural Studies of Science Education*, online first retrieved from: https://link.springer.com/article/10.1007/s11422-019-09962-7

Bencze, L., Sperling, E., & Carter, L. (2012). Students’ research-informed socio-scientific activism: Re/Visions for a sustainable future. *Research in Science Education*, *42*(1), 129–148. https://doi.org/10.1007/s11165-011-9260-3

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112. https://doi.org/10.1002/tea.21257

Bernholt, S., Eggert, S., & Kulgemeyer, C. (2012). Capturing the diversity of students' competences in science classrooms: Differences and commonalities of three complementary approaches. In S. Bernholt, K. Neumann, & P. Nentwig (Eds.), *Making it tangible: Learning outcomes in science education* (pp. 173–200). Münster: Waxmann.

[13] For a coherent presentation of all chapters (except Chapter 4), this dissertation uses APA 6th edition. The references used within the research articles and the manuscript can be found in the respective chapters (Chapter 4-6).

Besson, U., & Ambrosis, A. de (2014). Teaching energy concepts by working on themes of cultural and environmental value. *Science & Education*, *23*(2014), 1309–1338. https://doi.org/10.1007/s11191-013-9592-7

Betsch, T. (2008). The nature of intuition and its neglect in research on judgment and decision making. In H. Plessner, C. Betsch, & T. Betsch (Eds.), *Intuition in judgement and decision making*. New York, NY: Erlbaum.

Betsch, T., & Haberstroh, S. (2005a). Current research on routine decision making: Advances and prospects. In T. Betsch & S. Haberstroh (Eds.), *The routines of decision making* (pp. 359–376). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Betsch, T., & Haberstroh, S. (Eds.) (2005b). *The routines of decision making*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Bögeholz, S. (2007). Bewertungskompetenz für systematisches Entscheiden in komplexen Gestaltungssituationen nachhaltiger Entwicklung [Systematic decision-making in complex situations in sustainable development]. In D. Krüger & H. Vogt (Eds.), *Theorien in der biologiedidaktischen Forschung [Theories in biology education research]* (pp. 209–220). Berlin: Springer.

Bögeholz, S. (2016). Bewerten der Anwendung biologischer Erkenntnisse [Evaluating the application of biological knowledge]. In H. Gropengießer, U. Harms, & U. Kattmann (Eds.), *Fachdidaktik Biolgie [Didactics of biology]* (pp. 71–79). Hallbergmoos: Aulis Verlag.

Bögeholz, S., Eggert, S., Ziese, C., & Hasselhorn, M. (2017). Modeling and fostering decision-making competencies regarding challenging issues of sustainable development. In D. Leutner, J. Fleischer, J. Grünkorn, & E. Klieme (Eds.), *Competence Assessment in Education: Research, Models and Instruments* (pp. 263–284). Cham, Switzerland: Springer.

Bögeholz, S., Böhm, M., Eggert, S., & Barkmann, J. (2014). Education for sustainable development in German science education: Past – present – future. *EURASIA Journal of Mathematics, Science and Technology Education*, *10*(4). 231–248. https://doi.org/10.12973/eurasia.2014.1079a

Böhm, M., Eggert, S., Barkmann, J., & Bögeholz, S. (2016). Evaluating sustainable development solutions quantitatively: Competence modelling for GCE and ESD. *Citizenship, Social and Economics Education*, *15*(3), 190–211. https://doi.org/10.1177/2047173417695274

Böttcher, F., & Meisert, A. (2013). Effects of direct and indirect instruction on fostering decision-making competence in socioscientific issues. *Research in Science Education*, *43*(2), 479–506.

Bowmaker, M. (2006). Future ethical challenges in biology. *Journal on Science and World Affairs*, *2*(1), 43–50.

Brown, E., & Evans, W. P. (2002). Extracurricular activity and ethnicity: Creating greater school connection among diverse student populations. *Urban Education*, *37*(1), 41–58.

Brundtland Commission (1987). *Our common future*. Oxford, UK: Oxford University Press.

Burford, G., Hoover, E., Velasco, I., Janoušková, S., Jimenez, A., Piggot, G., . . . Harder, M. (2013). Bringing the “missing pillar” into sustainable development goals: Towards intersubjective values-based indicators. *Sustainability, 5*(7), 3035–3059. https://doi.org/10.3390/su5073035

Capkinoglu, E., Yilmaz, S., & Leblebicioglu, G. (2020). Quality of argumentation by seventh-graders in local socioscientific issues. *Journal of Research in Science Teaching*, 57(6), 827-855. https://doi.org/10.1002/tea.21609

Chang Rundgren, S.-N., & Rundgren, C.-J. (2010). SEE-SEP: From a separate to a holistic view of socioscientific issues. *Asia-Pacific Forum on Science Learning and Teaching*, *11*(1), 1–24.

Christenson, N., Chang Rundgren, S.-N., & Zeidler, D. L. (2014). The relationship of discipline background to upper secondary students' argumentation on socioscientific issues. *Research in Science Education*, *44*(4), 581–601. https://doi.org/10.1007/s11165-013-9394-6

Chung, Y., Yoo, J., Kim, S.-W., Lee, H., & Zeidler, D. L. (2016). Enhancing students' communication skills in the science classroom through socioscientific issues. *International Journal of Science and Mathematics Education*, *14*(1), 1–27. https://doi.org/10.1007/s10763-014-9557-6

Collins, S., Swinton, S., Anderson, C., Benson, B. J., Brunt, J., Gragson, T., . . . Whitmer, A. C. (2007). *Integrated science for society and the environment: A strategic research initiative.* Publication #23 of the U.S. LTER Network Office, retrieved from: https://lternet.edu/wp-content/themes/ndic/library/pdf/reports/ISSE_complete_30April.pdf

Colucci-Gray, L., Burnard, P., Gray, D., & Cooke, C. (2019). A critical review of STEAM (science, technology, engineering, arts, and mathematics). In P. Thomson (Ed.), *Oxford Research Encyclopedia of Education* (pp. 1–26). Oxford: Oxford University Press.

Dawson, V. (2015). Western Australian high school students' understandings about the socioscientific issue of climate change. *International Journal of Science Education*, *37*(7), 1024–1043. https://doi.org/10.1080/09500693.2015.1015181

Dawson, V., & Carson, K. (2020). Introducing argumentation about climate change socioscientific issues in a disadvantaged school. *Research in Science Education*, *50*(3), 863–883. https://doi.org/10.1007/s11165-018-9715-x

Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. *Research in Science Education*, *40*(2), 133–148. https://doi.org/10.1007/s11165-008-9104-y

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601.

DFG [Deutsche Forschungsgemeinschaft] (2016). *Animal Experimentation in Research*. Retrieved from: https://www.dfg.de/download/pdf/dfg_im_profil/geschaeftsstelle/publikationen/tierversuche_forschung_en.pdf

Dias, T. M., & Guedes, P. G. (2018). Student knowledge about the use of animals in scientific research. *Revista Bioética*, *26*(2), 235–244. https://doi.org/10.1590/1983-80422018262244

Dietrich, M. (2017). *Tierversuche verbieten? [Banning animal testing?]*. Ingolstadt: Eryn Verlag.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312.

Dunlop, L., & Veneu, F. (2019). Controversies in science: To teach or not to teach? *Science & Education*, *28*(6), 689–710. https://doi.org/10.1007/s11191-019-00048-y

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39–72. https://doi.org/10.1080/03057260208560187

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington D.C.: National Academies Press.

Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International Journal of Science Education*, *34*(15), 2289–2315. https://doi.org/10.1080/09500693.2012.667582

Eggert, S. (2016). Bewerten, Argumentieren und Entscheiden in komplexen Problemsituationen: Kompetenzen von Schülerinnen und Schülern (nicht nur) im Biologieunterricht [Evaluating, argumentation and decision-making in complex problems: Students' competencies (not only) in biology education]. In A. Sandmann & P. Schmiemann (Eds.), *Biologiedidaktische Forschung: Schwerpunkte und Forschungsstände [Research in biology education: Core themes and state of research]* (pp. 103–116). Berlin: Logos.

Eggert, S., & Bögeholz, S. (2006). Göttinger Modell der Bewertungskompetenz. Teilkompetenz "Bewerten, Entscheiden und Reflektieren" für Gestaltungsaufgaben Nachhaltiger Entwicklung [Göttinger competence model for socioscientific decision-making - competence dimension "evaluating and reflecting solutions qualitatively" in tasks related to sustainable development]. *Zeitschrift für Didaktik der Naturwissenschaften*, *12*(1), 177–199.

Eggert, S., & Bögeholz, S. (2010). Students' use of decision-making strategies with regard to socioscientific issues: An application of the Rasch partial credit model. *Science Education*, *94*(2), 230-258. https://doi.org/10.1002/sce.20358

Eggert, S., Nitsch, A., Boone, W. J., Nückles, M., & Bögeholz, S. (2017). Supporting students' learning and socioscientific reasoning about climate change: The effect of computer-based concept mapping scaffolds. *Research in Science Education*, *47*(1), 137–159. https://doi.org/10.1007/s11165-015-9493-7

Eggert, S., Ostermeyer, F., Hasselhorn, M., & Bögeholz, S. (2013). Socioscientific decision making in the science classroom: The effect of embedded metacognitive instructions on students' learning outcomes. *Education Research International*, *2013*(3), 1–12. https://doi.org/10.1155/2013/309894

Ekborg, M., Ottander, C., Silfver, E., & Simon, S. (2013). Teachers' experience of working with socio-scientific issues: A large scale and in depth study. *Research in Science Education*, *43*(2), 599–617. https://doi.org/10.1007/s11165-011-9279-5

Emery, K., Harlow, D., Whitmer, A., & Gaines, S. (2017). Compelling evidence: An influence on middle school students' accounts that may impact decision-making about socioscientific issues. *Environmental Education Research*, *23*(8), 1115–1129. https://doi.org/10.1080/13504622.2016.1225673

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, *88*(6), 915–933. https://doi.org/10.1002/sce.20012

Evagorou, M., Jiménez-Aleixandre, M. P., & Osborne, J. (2012). 'Should we kill the grey squirrels?': A study exploring students' justifications and decision-making. *International Journal of Science Education*, *34*(3), 401–428. https://doi.org/10.1080/09500693.2011.619211

Evagorou, M., Korfiatis, K., Nicolaou, C., & Constantinou, C. (2009). An investigation of the potential of interactive simulations for developing system thinking skills in elementary school: A case study with fifth-graders and sixth-graders. *International Journal of Science Education*, *31*(5), 655–674. https://doi.org/10.1080/09500690701749313

Exner, C., Bode, H.-J., Blumer, K. R., Giese, C., Winnacker, E.-L., & Gruss, P. (2004). *Tierversuche in der Forschung [Animal testing in research]*. Bonn: Lemmens Verlags- & Mediengesellschaft.

Faize, F. A., Husain, W., & Nisar, F. (2018). A critical review of scientific argumentation in science education. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(1). 475–483. https://doi.org/10.12973/ejmste/80353

Falk, J. H., Storksdieck, M., & Dierking, L. D. (2016). Investigating public science interest and understanding: Evidence for the importance of free-choice learning. *Public Understanding of Science*, *16*(4), 455–469. https://doi.org/10.1177/0963662506064240

Fang, S.-C., Hsu, Y.-S., & Lin, S.-S. (2019). Conceptualizing socioscientific decision making from a review of research in science education. *International Journal of Science and Mathematics Education*, *17*(3), 427–448.

Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R., . . . Eberle, J. (2014). Scientific reasoning and argumentation: Advancing an interdisciplinary research agenda in education. *Frontline Learning Research*, *5*(2014), 28–45.

Fleming, R. (1986). Adolsecent reasoning in socio-scientific issues. *Journal of Research in Science Teaching*, *23*(8), 677–687.

Forbes, L., & Billet, S. (2012). Successful co-teaching in the science classroom. *Science Scope*, *36*(1), 61–64.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404–423. https://doi.org/10.1002/sce.20263

Ford, M. J. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. *Cognition and Instruction*, *30*(3), 207–245. https://doi.org/10.1080/07370008.2012.689383

France, B., & Birdsall, S. (2015). Secondary students' attitudes to animal research: Examining the potential of a resource to communicate the scientist's perspective. *European Journal of Science and Mathematics Education*, *3*(3), 233–249.

Gerrard, M., Gibbons, X. F., Houlihan, A. E., Stock, M. L., & Pomery, E. A. (2008). A dual-process approach to health risk decision making: The prototype willingness model. *Developmental Review*, *28*(1), 29–61.

Gigerenzer, G., & Brighton, H. (2009). Homo heuristicus: Why biased minds make better inferences. *Topics in Cognitive Science*, *1*(1), 107–143. https://doi.org/10.1111/j.1756-8765.2008.01006.x

Glöckner, A., & Betsch, T. (2008). Modeling option and strategy choices with connectionist networks: Towards an integrative model of automatic and deliberate decision making. *Judgment and Decision Making*, *3*(3), 215–228.

Grace, M. (2009). Developing high quality decision-making discussions: About biological conservation in a normal classroom setting. *International Journal of Science Education*, *31*(4), 551–570. https://doi.org/10.1080/09500690701744595

Gresch, H., & Bögeholz, S. (2013). Identifying non-sustainable courses of action: A prerequisite for decision-making in education for sustainable development. *Research in Science Education*, *43*(2), 733–754. https://doi.org/10.1007/s11165-012-9287-0

Gresch, H., Hasselhorn, M., & Bögeholz, S. (2013). Training in decision-making strategies: An approach to enhance students' competence to deal with socio-scientific issues. *International Journal of Science Education*, *35*(15), 2587–2607. https://doi.org/10.1080/09500693.2011.617789

Haan, G. de (2010). The development of ESD-related competencies in supportive institutional frameworks. *International Review of Education*, *56*(2-3), 315–328. https://doi.org/10.1007/s11159-010-9157-9

Hawkes, J. (2001). *The Forth Pillar of Sustainability: Culture's Essential Role in Public Planning*. Melbourne, Australia: Common Ground Publishing.

Hedtke, R. (2016). Bildung zur Partizipation: Fachdidaktik als Auftragsnehmerin der Politik? [Education for participation: Education as contractor of the politics?]. In J. Menthe, D. Höttecke, T. Zabka, M. Hammann, & M. Rothgangel (Eds.), *Befähigung zu gesellschaftlicher Teilhabe: Beiträge der fachdidaktischen Forschung [Empowerment to participate in society: Contributions of didactic research]* (pp. 9–24). Münster: Waxmann.

Herman, B. C., Zeidler, D. L., & Newton, M. (2018). Students' emotive reasoning through place-based environmental socioscientific issues. *Research in Science Education*, online first retrieved from: https://link.springer.com/article/10.1007%2Fs11165-018-9764-1

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Higgins, J. P. T., & Green, S. (2011). *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0*. Retrieved from: www.handbook.cochrane.org

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education*, *25*(6), 645–670. https://doi.org/10.1080/09500690305021

Hofstein, A., Eilks, I., & Bybee, R. W. (2011). Societal issues and their importance for contemporary science education: A pedagogical justification and the state-of-the-art in

Israel, Germany, and the USA. *International Journal of Science and Mathematics Education*, *9*(6), 1459–1483.

Holbrook, J. (2005). Making chemestry teaching relevant. *Chemical Education International*, *6*(1), 1–12.

Holbrook, J., & Rannikmae, M. (2009). The meaning of scientific literacy. *International Journal of Environmental & Science Education*, *4*(3), 275–288.

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education*, *29*(11), 1347–1362. https://doi.org/10.1080/09500690601007549

Holstermann, N., Grube, D., & Bögeholz, S. (2009). The influence of emotion on students' performance in dissection exercises. *Journal of Biological Education*, *43*(4), 164–168. https://doi.org/10.1080/00219266.2009.9656177

Hößle, C., & Alfs, N. (2014). *Doping, Gentechnik, Zirkustiere: Bioethik im Unterricht [Doping, genetic engineering, circus animals: Bioethics in the classroom]*. Hallbergmoos: Aulis Verlag.

Hostenbach, J., Fischer, H. E., Kauertz, A., Mayer, J., Sumfleth, E., & Walpuski, M. (2011). Modellierung der Bewertungskompetenz in den Naturwissenschaften zur Evaluation der Nationalen Bildungsstandards [Modeling the evaluation and judgement competences in science to evaluate national educational standards]. *Zeitschrift für Didaktik der Naturwissenschaften*, *17*(1), 261–288.

Howes, E., & Cruz, B. (2009). Role-playing in science education: An effective strategy for developing multiple perspectives. *Journal of Elementary Science Education*, *21*(3), 33–46.

IPCC [Intergovernmental Panel on Climate Change] (2018). *Global warming of 1.5°C: Summary for policymakers.* Retrieved from: https://www.ipcc.ch/sr15/chapter/spm/

Jho, H., Yoon, H.-G., & Kim, M. (2014). The relationship of science knowledge, attitude and decision making on socio-scientific issues: The case study of students' debates on a nuclear power plant in Korea. *Science & Education*, *23*(5), 1131–1151. https://doi.org/10.1007/s11191-013-9652-z

Jiao, W. Y., Wang, L. N., Liu, J., Fang, S. F., Jiao, F. Y., Pettoello-Mantovani, M., & Somekh, E. (2020). Behavioral and emotional disorders in children during the COVID-19 epidemic. *The Journal of Pediatrics*, *221* (2020), 264-266. https://doi.org/10.1016/j.jpeds.2020.03.013

Jickling, B. (1992). Why I don't want my children to be educated for sustainable development. *Journal of Environmental Education*, *23*(4), 5–8.

Jiménez-Aleixandre, M. P., Rodríguez, A. B., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education*, *84*(6), 757–792.

Jiménez-Aleixandre, M. P., & Brocos, P. (2017). Processes of negotiation in socio-scientific argumentation about vegetarianism in teacher education. In F. Arcidiacono & A. Bova (Eds.), *Interpersonal argumentation in Educational and Professional contexts* (pp. 117–139). Cham, Switzerland: Springer.

Jiménez-Aleixandre, M.-P. (2002). Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. *International*

Journal of Science Education, *24*(11), 1171–1190. https://doi.org/10.1080/09500690210134857

Jiménez-Aleixandre, M.-P., & Erduran, S. (2008). Argumentation in science education: An overview. In S. Erduran & M.-P. Jiménez-Aleixandre (Eds.), *Argumentation in Science Education: Perspectives from Classroom-based Research* (pp. 3–27). Dordrecht: Springer.

Jungermann, H., Pfister, H.-R., & Fischer, K. (2005). *Die Psychologie der Entscheidung: Eine Einführung [The psychology of decision-making: An introduction]*. Heidelberg: Spektrum Akademischer Verlag.

Kahneman, D., & Frederick, S. (2002). Representativeness revisited: Attribute substitution in intuitive judgment. In D. Griffin & D. Kahneman (Eds.), *Heuristics and biases: The psychology of intuitive judgment* (pp. 49–81). Cambridge, UK: Cambridge University Press.

Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2020). Students' perceptions of socio-scientific issue-based learning and their appropriation of epistemic tools for systems thinking. *International Journal of Science Education*, *26*(2), 1–23. https://doi.org/10.1080/09500693.2020.1759843

Kelly, R., Sirr, L., & Ratcliffe, J. (2004). Futures thinking to achieve sustainable development at local level in Ireland. *Foresight*, *6*(2), 80–90. https://doi.org/10.1108/14636680410537547

Kim, M., Anthony, R., & Blades, D. (2014). Decision making through dialogue: A case study of analyzing preservice teachers' argumentation on socioscientific issues. *Research in Science Education*, *44*(6), 903–926. https://doi.org/10.1007/s11165-014-9407-0

Kiper, H., & Kattmann, U. (2003). Basiskompetenzen im Vergleich: Überblick über Ergebnisse der PISA-Studie 2000 [Comparing basic competencies: Overview of results of the PISA-study 2000]. In B. Moschner, H. Kiper, & U. Kattmann (Eds.), *PISA 2000 als Herausforderung: Perspektiven für Lehren und Lernen [PISA 2000 as a challenge: Perspectives for teaching and learning]* (pp. 15–38). Baltmannsweiler: Schneider Verlag Hohengehren.

Klosterman, M. L., & Sadler, T. D. (2010). Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *International Journal of Science Education*, *32*(8), 1017–1043. https://doi.org/10.1080/09500690902894512

KMK [Kultusministerkonferenz] (2005a). *Bildungsstandards im Fach Biologie für den Mittleren Bildungsabschluss [Education standards for biology education]*. München: Verlag Wolters Kluwer.

KMK [Kultusministerkonferenz] (2005b). *Bildungsstandards im Fach Chemie für den Mittleren Bildungsabschluss [Education standards for chemestry education]*. München: Verlag Wolters Kluwer.

KMK [Kultusministerkonferenz] (2005c). *Bildungsstandards im Fach Physik für den Mittleren Bildungsabschluss [Education standards for physics education]*. München: Verlag Wolters Kluwer.

KMK [Kultusministerkonferenz] (2019). *Standards für die Lehrerbildung: Bildungswissenschaften [Standards for teacher education: Educational science]*. Retrieved from: https://www.kmk.org/fileadmin/Dateien/veroeffentlichungen_beschluesse/2004/2004_12_16-Standards-Lehrerbildung-Bildungswissenschaften.pdf

Kohlberg, L. (1976). Moral stages and moralization: The cognitive development approach. In L. Kohlberg (Ed.), *Moral development and behavior* (pp. 31–53). New York, NY: Holt, Rinehart & Winston.

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, *85*(3), 291–310.

Kolstø, S. D. (2006). Patterns in students' argumentation confronted with a risk-focused socio-scientific issue. *International Journal of Science Education*, *28*(14), 1689–1716. https://doi.org/10.1080/09500690600560878

Kuckartz, U. (2014). *Mixed Methods: Methodolgie, Forschungsdesign und Analyseverfahren [Mixed Methods: Methodology, research designs and analysis]*. Weinheim: Beltz-Juventa.

Kunter, M., Klusmann, U., Baumert, J., Richter, D., Voss, T., & Hachfeld, A. (2013). Professional competence of teachers: Effects on instructional quality and student development. *Journal of Educational Psychology*, *105*(3), 805–820. https://doi.org/10.1037/a0032583

Langhelle, O. (1999). Sustainable development: Exploring the ethics of Our Common Future. *International Political Science Review*, *20*(2), 129–149.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, *84*(1), 71–94.

Law, M., Stewart, D., Letts, L., Pollock, N., Bouch, J., & Westmorland, M. (2007). *Critical Review Form: Quantitative Review Form*. Retrieved from: https://www.unisa.edu.au/Global/Health/Sansom/Documents/iCAHE/CATs/McMasters_Quantitative%20review.pdf

Lederman, N. G., Antink, A., & Bartos, S. (2014). Nature of science, scientific inquiry, and socio-scientific issues arising from genetics: A pathway to developing a scientifically literate citizenry. *Science & Education*, *23*(2), 285–302. https://doi.org/10.1007/s11191-012-9503-3

Lee, H., Abd-El-Khalick, F., & Choi, K. (2006). Korean science teachers' perceptions of the introduction of socio-scientific issues into the science curriculum. *Canadian Journal of Science, Mathematics and Technology Education*, *6*(2), 97–117.

Lee, H., & Witz, K. G. (2009). Science teachers' inspiration for teaching socio-scientific issues: Disconnection with reform efforts. *International Journal of Science Education*, *31*(7), 931–960. https://doi.org/10.1080/09500690801898903

Lee, H., Lee, H., & Zeidler, D. L. (2019). Examining tensions in the socioscientific issues classroom: Students' border crossings into a new culture of science. *Journal of Research in Science Teaching*, *57*(5), 672–694. https://doi.org/10.1002/tea.21600

Lee, Y. C. (2007). Developing decision-making skills for socio-scientific issues. *Journal of Biological Education*, *41*(4), 170–177. https://doi.org/10.1080/00219266.2007.9656093

Lee, Y. C., & Grace, M. (2010). Students' reasoning processes in making decisions about an authentic, local socio-scientific issue: Bat conservation. *Journal of Biological Education*, *44*(4), 156–165. https://doi.org/10.1080/00219266.2010.9656216

Lee, Y. C., & Grace, M. (2012). Students' reasoning and decision making about a socioscientific issue: A cross-context comparison. *Science Education*, *96*(5), 787–807. https://doi.org/10.1002/sce.21021

Lemke, J. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex.

Letts, L., Wilkins, S., Law, M., Stewart, D., Bosch, J., & Westmorland, M. (2007). *Guidelines for Critical Review Form: Qualitative Studies*. Retrieved from: https://www.unisa.edu.au/contentassets/72bf75606a2b4abcaf7f17404af374ad/7b-mcmasters_qualreview_version2-01.pdf

Levinson, R. (2004). Teaching bioethics in science: Crossing a bridge too far? *Canadian Journal of Science, Mathematics and Technology Education*, *4*(3), 353–369.

Levinson, R. (2013). Practice and theory of socio-scientific issues: An authentic model? *Studies in Science Education*, *49*(1), 99–116. https://doi.org/10.1080/03057267.2012.746819

Lindahl, M. G., Folkesson, A.-M., & Zeidler, D. L. (2019). Students' recognition of educational demands in the context of a socioscientific issues curriculum. *Journal of Research in Science Teaching*, *56*(9), 1155–1182. https://doi.org/10.1002/tea.21548

Little, A. W., & Green, A. (2009). Successful globalisation, education and sustainable development. *International Journal of Educational Development*, *29*(2), 166–174. https://doi.org/10.1016/j.ijedudev.2008.09.011

Liu, S.-Y., Lin, C.-S., & Tsai, C.-C. (2011). College students' scientific epistemological views and thinking patterns in socioscientific decision making. *Science Education*, *95*(3), 497–517. https://doi.org/10.1002/sce.20422

Löschke, J. (2015). Zentrale Begriffe und Konzepte der Bioethik [Central terms and concepts of in bioethics]. In D. Sturma & B. Heinrichs (Eds.), *Handbuch Bioethik [Handbook of bioethics]* (pp. 21–25). Stuttgart: J.B. Metzler.

Lyons, T. (2006). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education*, *36*(3), 285–311. https://doi.org/10.1007/s11165-005-9008-z

Mahler, D., Großschedl, J., & Harms, U. (2017). Using doubly latent multilevel analysis to elucidate relationships between science teachers’ professional knowledge and students’ performance. *International Journal of Science Education*, *39*(2), 213–237. https://doi.org/10.1080/09500693.2016.1276641

Mansour, N. (2009). Science-Technology-Society (STS): A new paradigm in science education. *Bulletin of Science, Technology & Society*, *29*(4), 287–297. https://doi.org/10.1177/0270467609336307

McBeth, W., & Volk, T. L. (2009). The national environmental literacy project: A baseline study of middle grade students in the United States. *The Journal of Environmental Education*, *41*(1), 55–67. https://doi.org/10.1080/00958960903210031

Means, M., & Voss, J. (1996). Who reasons well? : Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction*, *14*(2), 139–178.

Mercier, H., Boudry, M., Paglieri, F., & Trouche, E. (2017). Natural-born arguers: Teaching how to make the best of our reasoning abilities. *Educational Psychologist*, *52*(1), 1–16. https://doi.org/10.1080/00461520.2016.1207537

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching*, *55*(7), 1053–1075. https://doi.org/10.1002/tea.21459

Mittelsten Scheid, N. (2009). Argumentation aus metakognitiver Perspektive: Leitlinien für Maßnahmen zur Professionsentwicklung naturwissenschaftlicher Lehrkräfte [Skills of argument from a metacognitive perspective - outlining science teacher education]. *Zeitschrift für Didaktik der Naturwissenschaften*, *15*(1), 173–193.

Mittenzwei, D., Bruckermann, T., Nordine, J., & Harms, U. (2019). The energy concept and its relation to climate literacy. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(6), em1703. https://doi.org/10.29333/ejmste/105637

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Physical Therapy*, *89*(9), 873–880.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., . . . Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, *4*(1), 1–9.

Morin, O., Simonneaux, L., Simonneaux, J., & Tytler, R. (2013). Digital technology to support students' socioscientific reasoning about environmental issues. *Journal of Biological Education*, *47*(3), 157–165. https://doi.org/10.1080/00219266.2013.821748

Moschner, B. (2003). Wissenserwerbprozesse und Didaktik [Processes of knowledge acquisition and didactics]. In B. Moschner, H. Kiper, & U. Kattmann (Eds.), *PISA 2000 als Herausforderung: Perspektiven für Lehren und Lernen [PISA 2000 as a challenge: Perspectives for teaching and learning]* (pp. 53–64). Baltmannsweiler: Schneider Verlag Hohengehren.

Mueller, M. P., Tippins, D. J., & Stewart, A. J. (Eds.) (2017). *Animals and Science Education: Ethics, Curriculum and Pedagogy*. Cham, Switzerland: Springer.

National Research Council (2001). *Knowing what students know*. Washington D.C.: National Academies Press.

Neumann, K., Bernholt, S., & Nentwig, P. (2012). Learning outcomes in science education: A synthesis of the international views on defining, assessing and fostering science learning. In S. Bernholt, K. Neumann, & P. Nentwig (Eds.), *Making it tangible: Learning outcomes in science education* (pp. 501–519). Münster: Waxmann.

NGSS [Next Generation Science Standards] (2013). *Next Generation Science Standards: For States, by States*. Washington, D.C.: The National Academies Press.

Nielsen, J. A. (2012). Science in discussions: An analysis of the use of science content in socioscientific discussions. *Science Education*, *96*(3), 428–456. https://doi.org/10.1002/sce.21001

NRC [National Research Council] (2012). *A Framework for K-12 Science Education: Practices, crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academies Press.

Nuffield Council on Bioethics (2005). *The ethics of research involving animals.* Retrieved from: https://www.nuffieldbioethics.org/publications/animal-research

OECD [Organization for Economic Cooperation and Development] (2019). *OECD Future of Education and Skills 2030: OECD Learning Compass 2030*. Retrieved from https://www.oecd.org/education/2030-project/contact/OECD_Learning_Compass_2030_Concept_Note_Series.pdf

Olsson, D., Gericke, N., & Chang Rundgren, S.-N. (2015). The effect of implementation of education for sustainable development in Swedish compulsory schools: Assessing pupils' sustainability consciousness. *Environmental Education Research*, *22*(2), 176–202. https://doi.org/10.1080/13504622.2015.1005057

Orpwood, G. (2001). The role of assessment in science curriculum reform. *Assessment in Education: Principles, Policy & Practice*, *8*(2), 135–151. https://doi.org/10.1080/09695940125120

Orpwood, G. (2007). Assessing scientific literacy: Threats and opportunities. In C. Linder, L. Ostman, & P.-O. Wickman (Chairs), *Promoting scientific literacy: Science education research in transaction. Proceedings of the Linnaeus Tercentenary Symposium.* (pp. 120-129). Uppsala, Sweden: Uppsala University.

Osborne, J. (2007). Science education for the twenty first century. *EURASIA Journal of Mathematics, Science and Technology Education, 3*(3). https://doi.org/10.12973/ejmste/75396

Osborne, J., & Collins, S. (2001). Pupils' views of the role and value of the science curriculum: A focus-group study. *International Journal of Science Education, 23*(5), 441–467. https://doi.org/10.1080/09500690010006518

Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. London: The Nuffield Foundation.

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638. https://doi.org/10.1002/sce.20438

Owens, D. C., Sadler, T. D., & Zeidler, D. L. (2017). Controversial issues in the science classroom. *Phi Delta Kappan*, *99*(4), 45–49. https://doi.org/10.1177/0031721717745544

Paakkari, L., & Okan, O. (2020). COVID-19: Health literacy is an underestimated problem. *The Lancet Public Health*, *5*(5), e249–e250. https://doi.org/10.1016/S2468-2667(20)30086-4

Paul, J., Lederman, N. G., & Groß, J. (2016). Learning experimentation through science fairs. *International Journal of Science Education*, *38*(15), 2367–2387. https://doi.org/10.1080/09500693.2016.1243272

Pedersen, J. E., & Totten, S. (2001). Beliefs of science teachers toward the teaching of science/technological/social issues: Are we addressing national standards? *Bulletin of Science, Technology & Society*, *21*(5), 376–393.

Pedretti, E. (2003). Teaching science, technology, society and environment (STSE) education. In D. Zeidler (Ed.), *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education* (pp. 219–239). Amsterdam: Springer.

Pellegrino, J. W. (2012). The design of an assessment system focused on students achievement: A learning sciences perspective on issues of competence, growth, and measurement. In S. Bernholt, K. Neumann, & P. Nentwig (Eds.), *Making it tangible: Learning outcomes in science education* (pp. 79–107). Münster: Waxmann.

Perry, P. (2007). The ethics of animal research: A UK perspective. *Institute for Laboratory Animal Research Journal*, *48*(1), 42–46.

Petersen, S., & Wulff, P. (2017). The German physics olympiad: Identifying and inspiring talents. *European Journal of Physics*, *38*(3), 1–16. https://doi.org/10.1088/1361-6404/aa538f

Pike, L., Shannon, T., Lawrimore, K., McGee, A., Taylor, M., & Lamoreaux, G. (2003). Science education and sustainability initiatives: A campus recycling case study shows the importance of opportunity. *International Journal of Sustainability in Higher Education*, *4*(3), 218–229. https://doi.org/10.1108/14676370310485410

Pope, T. (2017). Socioscientific issues: A framework for teaching ethics through controversial issues in science. *Teach*, *11*(2), 42–49.

Prout, A. (2001). Representing children: Reflections on the children 5-16 programme. *Children & Society*, *15*(3), 193–201. https://doi.org/10.1002/chi.667

Prout, A. (2002). Researching children as social actors: An introduction to the children 5-16 programme. *Children & Society*, *16*(2), 67–76. https://doi.org/10.1002/chi.710

Ratcliffe, M. (1997). Pupil decision-making about socio-scientific issues within the science curriculum. *International Journal of Science Education*, *19*(2), 167–182.

Ratcliffe, M., & Grace, M. (2003). *Science education for citizenship: Teaching socio-scientific issues*. Maidenhead: Open University Press.

Reis, P., & Galvao, C. (2004). The impact of socio-scientific controversies in portuguese natural science teachers' conceptions and practices. *Research in Science Education*, *34*(2004), 153–171.

Reiss, M. J. (2017). A framework within which to determine how we should use animals in science education. In M. P. Mueller, D. J. Tippins, & A. J. Stewart (Eds.), *Animals and Science Education: Ethics, Curriculum and Pedagogy* (pp. 243–260). Cham, Switzerland: Springer.

Reitschert, K., & Hößle, C. (2007). Wie Schüler ethisch bewerten: Eine qualitative Untersuchung zur Strukturierung und Ausdifferenzierung von Bewertungskompetenz in bioethischen Sachverhalten bei Schülern der Sek. I [How students judge ethically: A qualitative study on the structure and differentiation of competence of moral judgement with respect to bioethical issues concerning students of Sek. I]. *Zeitschrift für Didaktik der Naturwissenschaften*, *13*(1), 125–142.

Reitschert, K., Langlet, J., Hößle, C., Mittelsten Scheid, N., & Schlüter, K. (2007). Dimensionen ethischer Urteilskompetenz: Dimensionierung und Niveaukonkretisierung [Dimensions of ethical judgment competency: Dimensions and niveaus]. *Mathematisch Naturwissenschaftlicher Unterricht*, *60*(1), 43–51.

Roberts, D. A. (2007). Scientific literacy/science literacy. In Sandra K. Abell & Norman G. Lederman (Ed.), *Handbook of research on science education* (pp. 729–780). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, science literacy, and science education. In Norman G. Lederman & Sandra K. Abell (Ed.), *Handbook of research on science education: Volume II* (pp. 545–558). New York, NY: Routledge.

Robson, C. (2011). *Real world research: A resource for users of social research methods in applied settings* (Third edition). Chichester, UK: Wiley.

Romine, W. L., Sadler, T. D., & Kinslow, A. T. (2017). Assessment of scientific literacy: Development and validation of the Quantitative Assessment of Socio-Scientific Reasoning (QuASSR). *Journal of Research in Science Teaching*, *54*(2), 274–295. https://doi.org/10.1002/tea.21368

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536. https://doi.org/10.1002/tea.20009

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1–42. https://doi.org/10.1080/03057260802681839

Sadler, T. D. (Ed.) (2011). *Socio-scientific issues in the classroom: Teaching, learning and research*. Dordrecht: Springer.

Sadler, T. D., Amirshokoohi, A., Kazempour, M., & Allspaw, K. M. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching*, *43*(4), 353–376. https://doi.org/10.1002/tea.20142

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371–391. https://doi.org/10.1007/s11165-006-9030-9

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2007). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, *26*(4), 387–409. https://doi.org/10.1080/0950069032000119456

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, *88*(1), 4–27. https://doi.org/10.1002/sce.10101

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1), 112–138. https://doi.org/10.1002/tea.20042

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching*, *46*(8), 909–921. https://doi.org/10.1002/tea.20327

Sakschewski, M., Eggert, S., Schneider, S., & Bögeholz, S. (2014). Students' socioscientific reasoning and decision-making on energy-related issues: Development of a measurement instrument. *International Journal of Science Education*, *36*(14), 2291–2313. https://doi.org/10.1080/09500693.2014.920550

Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, *92*(3), 447–472. https://doi.org/10.1002/sce.20276

Sartori, S., Da Silva, F. L., & Capos, L. (2014). Sustainability and sustainable development: A taxonomy in the field of literature. *Ambiente Sociedade*, *17*(1), 1–22.

Saunders, K. J., & Rennie, L. J. (2013). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education*, *43*(1), 253–274. https://doi.org/10.1007/s11165-011-9248-z

Schecker, H. (2012). Standards, competencies and outcomes: A critical view. In S. Bernholt, K. Neumann, & P. Nentwig (Eds.), *Making it tangible: Learning outcomes in science education* (pp. 219–234). Münster: Waxmann.

Schimmenti, A., Billieux, J., & Starcevic, V. (2020). The four horsemen of fear: An integrated model of understanding fear experiences during the COVID-19 pandemic. *Clinical Neuropsychiatry*, *17*(2), 41–45.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education*, *90*(4), 605–631. https://doi.org/10.1002/sce.20131

Simon, S., & Amos, R. (2011). Decision making and use of evidence in a socio-scientific problem on air quality. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 167–192). Dordrecht: Springer.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, *28*(2-3), 235–260. https://doi.org/10.1080/09500690500336957

Simonneaux, L., & Simonneaux, J. (2009). Socio-scientific reasoning influenced by identities. *Cultural Studies of Science Education*, *4*(3), 705–711. https://doi.org/10.1007/s11422-008-9145-6

Stefanou, C. R., Perencevich, K. C., DiCintio, M., & Turner, J. C. (2004). Supporting autonomy in the classroom: Ways teachers encourage student decision making and ownership. *Educational Psychologist*, *39*(2), 97–110. https://doi.org/10.1207/s15326985ep3902_2

Stolz, M., Witteck, T., Marks, R., & Eilks, I. (2013). Reflecting socio-scientific issues for science education coming from the case of curriculum development on doping in chemistry education. *EURASIA Journal of Mathematics, Science and Technology Education*, *9*(4). https://doi.org/10.12973/eurasia.2014.945a

Tal, T., Kali, Y., Magid, S., & Madhok, J. J. (2011). Enhancing the authenticity of a web-based module for teaching simple inheritance. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 11–38). Dordrecht: Springer.

Tidemand, S., & Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: From the perspective of teachers. *International Journal of Science Education*, *39*(1), 44–61. https://doi.org/10.1080/09500693.2016.1264644

Toulmin, S. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

Udell, W. (2007). Enhancing adolescent girls' argument skills in reasoning about personal and non-personal decisions. *Cognitive Development*, *22*(3), 341–352. https://doi.org/10.1016/j.cogdev.2007.02.003

Vare, P., & Scott, W. (2007). Learning for a change: Exploring the relationship between education and sustainable development. *Journal of Education for Sustainable Development*, *1*(2), 191–198. https://doi.org/10.1177/097340820700100209

Walker, K. A., & Zeidler, D. L. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International Journal of Science Education*, *29*(11), 1387–1410. https://doi.org/10.1080/09500690601068095

Walton, D. (2006). *Fundamentals of Critical Argumentation*. Cambridge, UK: Cambridge University Press.

Weinert, F. E. (2001). Concept of competence: A conceptual clarification. In S. D. Rychen & L. H. Salganik (Eds.), *Defining and selecting key competencies* (pp. 45–64). Ashland, OH, US: Hogrefe & Huber Publishers.

White, R. (2011). Climate change, uncertain futures and the sociology of youth. *Youth Studies Australia*, *30*(3), 13–19.

Wilson, R., & Keil, F. (2001). *MIT encyclopedia of the cognitive sciences*. Cambridge, UK: MIT Press.

Wu, Y.-T., & Tsai, C.-C. (2007). High school students' informal reasoning on a socio-scientific issue: Qualitative and quantitative analyses. *International Journal of Science Education*, *29*(9), 1163–1187. https://doi.org/10.1080/09500690601083375

Yager, R. E. (1993). Science-Technology-Society as reform. *School Science and Mathematics*, *93*(3), 145–151.

Yoon, S. A. (2011). Using social network graphs as visualization tools to influence peer selection decision-making strategies to access information about complex socioscientific issues. *Journal of the Learning Sciences*, *20*(4), 549–588. https://doi.org/10.1080/10508406.2011.563655

You, H. S. (2017). Why teach science with an interdisciplinary approach: History, trends, and conceptual frameworks. *Journal of Education and Learning*, *6*(4), 66. https://doi.org/10.5539/jel.v6n4p66

Zacharia, Z., & Calabrese Barton, A. (2004). Urban middle-school students' attitudes toward a defined science. *Science Education*, *88*(2), 197–222. https://doi.org/10.1002/sce.10110

Zeidler, D., & Keefer, M. (2003). The role of moral reasoning and the status of socioscientific issues in science education. In D. Zeidler (Ed.), *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education* (pp. 7–40). Amsterdam: Springer.

Zeidler, D., & Lewis, J. (2003). Unifying themes in moral reasoning on socioscientific issues and discourse. In D. Zeidler (Ed.), *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education* (pp. 289–306). Amsterdam: Springer.

Zeidler, D. L. (2014). Socioscientific issues as a curriculum emphasis: Theory, research and practice. In Norman G. Lederman & Sandra K. Abell (Ed.), *Handbook of research on science education: Volume II* (pp. 697–726). New York, NY: Routledge.

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education*, *11*(1), 11–26. https://doi.org/10.1007/s11422-014-9578-z

Zeidler, D. L., Applebaum, S. M., & Sadler, T. D. (2011). Enacting a socioscientific issues classroom : Transformative transformations. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 277–312). Dordrecht: Springer.

Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–19. https://doi.org/10.1186/s43031-019-0008-7

Zeidler, D. L., & Sadler, T. D. (2008). Social and ethical issues in science education: A prelude to action. *Science & Education*, *17*(8-9), 799–803. https://doi.org/10.1007/s11191-007-9130-6

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through socioscientific issues. *Journal of Research in Science Teaching*, *46*(1), 74–101. https://doi.org/10.1002/tea.20281

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, *89*(3), 357–377. https://doi.org/10.1002/sce.20048

Zeng, Z., Fan, X., Miao, C., Leung, C., Jih, C. J., & Soon, O. Y. (2018). Context-based and explainable decision making with argumentation. In M. Dastani, G. Sukthankar, E. André, & S. Koenig (Chairs), *Proc. of the 17th International Conference on Autonomous Agens and Multiagent Systems,* Stockholm, Sweden. Retrieved from: http://ifaamas.org/Proceedings/aamas2018/pdfs/p1114.pdf

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*(1), 35–62. https://doi.org/10.1002/tea.10008

11. SUPPLEMENTARY MATERIAL

11.1. Associated master theses

This dissertation project has been supported by three master thesis projects. Table 11.1 provides an overview of the three qualification works and their role for this dissertation.

Table 11.1: Overview of associated qualification works.

Author of the thesis	Title of thesis	Submission	Note
Hassel, L.	Tierversuche verstehen und bewerten im Biologieunterricht – Generierung eines Kriterienkatalogs zur Auswahl und Gestaltung effektiver Unterrichtsmaterialien und Entwicklung eines Best-Practice-Moduls für die Sekundarstufe I zur Förderung von Bewertungskompetenz [Understanding and negotiating animal testing in biology education – The development of a catalogue of criteria for the selection and the design of effective teaching materials and the development of a best-practice-unit for secondary education (Sekundarstufe I) for the promotion of socioscientific decision-making]	03/2018	Development of a catalogue of criteria used as a basis for the development of the teaching unit. Development of the teaching unit that was implemented within Study 3.
Regenstein, V.	Tierversuche verstehen und bewerten im Biologieunterricht – Die Erarbeitung eines Kriterienkatalogs zur Auswahl und Anfertigung von Unterrichtsmaterial zur Förderung von Bewertungskompetenz anhand eines Best-Practice-Moduls für die Sekundarstufe II [Understanding and negotiating animal testing in biology education – The development of a catalogue of criteria for the selection and the design of teaching materials for the promotion of socioscientific decision-making in a best-practice-unit for upper secondary school students (Sekundarstufe II)]	03/2018	Development of a catalogue of criteria used as a basis for the development of the teaching unit (Study 3).
Burkhardt, J.	Ethisches Bewerten im Biologieunterricht – Die Argumentation von Schülerinnen und Schüler im Diskurs über Tierversuche [Ethical decision-making in biology education – Students' argumentation regarding animal testing]	01/2020	Interrating and first insights into students' argumentation patterns (Study 3).

11.2. Instruments used within the conducted studies

Three different instruments have been used within the conducted studies of this dissertation.

11.2.1. The instruments used within Study 2

11.2.1.1. The instrument used within sub-study 1

Participants of Study 2 were given a 45-minute paper-and-pencil questionnaire on socioscientific decision-making by Eggert and Bögeholz (2010). All rights are reserved to these authors. For details about the instrument see also: https://www.fdz-bildung.de/test.php?la=de&id=18.

Exemplary items as well as more detailed information on how to score students' answers are provided in:

Eggert, S. & Bögeholz, S. (2010). Students' use of decision-making strategies with regard to socioscientific issues: An application of the Rasch partial credit model. *Science Education, 94*(2), 230-258.

Gresch, H., Hasselhorn, M., & Bögeholz, S. (2013). Training in decision-making strategies: An approach to enhance students' competence to deal with socio-scientific issues. *International Journal of Science Education, 35*(15), 2587-2607.

11.2.1.2. The interview guideline used within sub-study 2

In the following, the 26 interview questions that investigated participants' experiences with decision-making during the competition are presented[14]. The interview guideline is divided into four sections. Interviews lasted about 30 minutes and were conducted individually.

Introductory text [not displayed within this dissertation]

Section 1: Contextualization

1. Würdest du mir bitte in einigen Sätzen erzählen, warum ihr euch entschieden habt, beim BUW teilzunehmen?
   [*Would you please tell me, in a couple of sentences, why you have decided to participate in the BUW?*]
2. Bitte erzähle mir in zwei bis drei Sätzen, welches Projekt ihr beim BUW eingereicht habt.
   [*Please tell me in two or three sentences, what kind of project you have submitted to the BUW.*]
3. Gibt es einen speziellen Grund, warum ihr dieses Thema ausgewählt habt?
   [*Is there a particular reason why you have chosen this topic?*]
4. Gab es noch andere Themen, die für euch in Frage kamen?
   [*Have there been other topics that were also from interest to you?*]
5. BUW steht für BundesUmweltWettbewerb. Inwiefern spielt das Thema Umwelt beziehungsweise Nachhaltigkeit eine Rolle in eurem Projekt?

[14] The interview was conducted in German. The translated questions are only for reviewing purposes.

[*BUW is short for BundesUmweltWettbewerb. To what degree do the themes 'environment' and 'sustainability' play a role in your project?*]

6. Wieso glaubst du, gibt es solche Wettbewerbe wie den BUW, welche sich auf die Förderung nachhaltiger Ideen fokussieren?
   [*What do you think, why do we have competitions like the BUW which focus on the promotion of 'green' ideas?*]

Section II: Reflecting upon your individual BUW-project

7. Ihr habt viel Zeit und Arbeit in euer Projekt investiert. Beschreibe bitte einmal die Anfänge eurer Projektarbeit, also nachdem ihr euch auf euer Thema festgelegt habt. Wie seid ihr dann im nächsten Schritt an Informationen zum Thema gelangt?
   [*You have invested a lot of time and work into your project. Please describe the beginnings of your project work after you have decided on a topic. How did you collect the necessary information?*]
8. Habt ihr während der Projektarbeit gemeinsam mit Experten gearbeitet? Oder an wen habt ihr euch gewendet, wenn ihr nicht weiter wusstet?
   [*While working on your project, have you been collaborating with experts? Who did you turn to when you needed help?*]
9. Habt ihr Daten für euer Projekt gesammelt bzw. ausgewertet? Wenn ja, kannst du beschreiben, wie ihr dabei vorgegangen seid?
   [*Have you collected and analyzed data for your project? If so, can you explain how you proceeded?*]
10. Konntet ihr dann aus den gesammelten Daten ablesen, was als nächstes zu tun ist? Also, konntet ihr Handlungsoptionen ableiten?
    [*Were you able to use the data to conclude what to do next? In other words, could you conclude further steps of action?*]
11. Wie habt ihr dann schließlich euer „Projektproblem“ gelöst?
    [*How did you, eventually, solve the key problem of your project?*]
12. Seid ihr eher intuitiv vorgegangen oder habt ihr eure Schritte sorgfältig geplant?
    [*Did you proceed rather intuitively or did you plan your steps carefully?*]
13. Seid ihr während der Untersuchung systematisch vorgegangen oder habt ihr auch mal spontan Entscheidungen gefällt?
    [*During the project-related investigations, did you proceed rather systematically or did you also make spontaneous decisions?*]
14. Gab es auch mal Uneinigkeiten im Team darüber, was man als nächstes tun sollte? Woran, glaubst du, lag das?
    [*Was there ever any disagreement about what to do next? What do you think was the reason?*]
15. Um das Projekt letztendlich beim BUW einzureichen, musstet ihr auch eine Projektarbeit schreiben. Wie seid ihr beim Schreiben vorgegangen? Habt ihr den Leitfaden zur Hilfe genommen, um die Projektarbeit anzufertigen?
    [*To submit the project to the BUW, you also had to write a project report. How did you proceed with writing? Have you used the BUW-guideline to write the report?*]

Section III: Development of participants' socioscientific decision-making

16. Versuche dich nun bitte einmal in die Zeit <u>vor</u> der BUW-Teilnahme zu versetzen. Wusstest du vor der Teilnahme am BUW, was Nachhaltigkeit bedeutet? Oder anders gesagt, wie würdest du dein Verständnis von Nachhaltigkeit <u>vor</u> dem BUW beschreiben?
    [*Please try to recall the time <u>before</u> participating in the BUW. Did you know what 'sustainability' means before participating in the BUW? In other words, how would you describe your understanding of 'sustainability' <u>before</u> the BUW?*]

17. Und wenn du jetzt an die Zeit nach eurer BUW-Teilnahme denkst: Glaubst du, du hast etwas über Nachhaltigkeit gelernt, was du vorher nicht wusstest?
    [*Now try to recall the time after participating in the BUW: Do you think you have learned something about sustainability that you did not know beforehand?*]
18. Hast du durch die Projektarbeit etwas über das Arbeiten im Team gelernt?
    [*Have you learned something about working in a team during the project work?*]
19. Täglich muss man viele Entscheidungen treffen. Auch bei der Bearbeitung von Umweltproblemen im Rahmen des BUW müssen schwierige Entscheidungen getroffen werden. Wenn man begründet zwischen verschiedenen Möglichkeiten abwägen kann und sowohl Vor- als auch Nachteile jeder Möglichkeit dabei einbezieht, dann nennt man das Bewertungskompetenz, also deine Fähigkeit zum Bewerten und Beurteilen von Sachverhalten oder Situationen. Glaubst du, deine Fähigkeit zum Bewerten von Situationen - zum Beispiel eurer Projektsituation - wurde durch den BUW gefördert?
    [*We have to make numerous decisions on a daily base. Negotiating environmental problems as part of your competition participation also required making decisions. The ability to evaluate different courses of action while considering their advantageous and disadvantageous features is called socioscientific decision-making: It describes the ability to evaluate situations and circumstances. Do you think participating in the BUW promoted your socioscientific decision-making?*]
20. Wenn ja, durch welche Projektphasen des Wettbewerbs wurde deine Bewertungskompetenz besonders gefördert?
    [*If so, in which of the competition's phases has your socioscientific decision-making been promoted?*]
21. Der BUW ist ein Projektwettbewerb. Auch ihr habt für euer Projekt in einer Gruppe zusammengearbeitet. Hat jede/r von euch verschiedene Rollen in der Projektarbeit eingenommen?
    [*The BUW is a project-oriented competition. For your project, you have worked in a group. Have you had different roles for each member of your group?*]
22. Habt ihr Entscheidungen im Rahmen eures Projekts gemeinsam getroffen?
    [*Did you make joint decisions during your project work?*]
23. Kannst du mir ein Beispiel nennen, bei welcher ihr euch zwischen verschiedenen Handlungsoptionen entscheiden musstet?
    [*Can you name an example which required you to choose between different courses of action?*]
24. Gab es etwas, das du von deinen Gruppenmitgliedern gelernt hast in der Zeit der Projektbearbeitung?
    [*Is there something that you have learned from your group members during the project work?*]

Section IV: Conclusion

25. In der Schule gibt es ja auch manchmal die Möglichkeit Projekte zu bearbeiten, zum Beispiel in den Schulstunden. Was war anders bei der Projektbearbeitung im Rahmen des BUW?
    [*There are also opportunities for project work within the regular school setting, e.g., the classroom. What was different about the project work associated with the BUW?*]
26. Ganz generell, was würdest du sagen, hast du durch die Teilnahme am BUW gelernt?
    [*In general, do you think you have learned something from participating in the BUW?*]

11.2.2. The instrument used within Study 3

The questionnaire implemented within Study 3 consists of four open-ended items. Students were asked to answer in full sentences and in written format. The questionnaire will be displayed in German (see 11.2.2.1) and in English (see 11.2.2.2) language.

11.2.2.1. The questionnaire in German language[15]

Item 1:

Lukas ist sechs Monate alt und verfügt über 50 Prozent des normalen Hörvermögens. Bei seiner Form der Hörstörung ist der Hörnerv zwar intakt, jedoch ist die Weiterleitung des akustischen Signals über die Hörschnecke im Innenohr beeinträchtigt. Folglich besteht das Risiko, dass Lukas gesamte und vor allem sprachliche Entwicklung davon beeinflusst sein könnte.
Neurowissenschaftler arbeiten an einer neuen Form der Cochlea Implantate die betroffenen Menschen wie Lukas helfen könnten. Dabei handelt es sich um eine Prothese, die operativ eingesetzt wird und die Funktion des Innenohrs übernimmt. An Tieren in Laboren, darunter Mäuse und Affen, werden optische Cochlea Implantate entwickelt, um durch Licht den Hörnerv zu reizen. Dafür wird den Tieren zunächst ein Implantat eingesetzt und danach ein Grünalgen-Gen in die Nervenzellen eingeschleust, welche dadurch lichtempfindlich werden. Diese neuartigen optischen Cochlea Implantate wandeln den Schall in Licht um, wodurch die Hörqualität von Betroffenen verbessert wird.

Lies dir den Text gut durch. Welches Dilemma wird hier aufgezeigt?

Item 2:

Stell dir vor, man würde darüber entscheiden, ob wir Tierversuche in Deutschland abschaffen sollten. Wärst du dafür oder dagegen? Entscheide dich und nenne mindestens drei Argumente für deine gewählte Position.

Item 3:

Es gibt Leute, die sich anders entscheiden als du. Wer könnten diese Personen sein und mit welchen Argumenten vertreten diese Personen ihre Meinung?

Item 4:

Xenotransplantation stellt eine prinzipielle Möglichkeit im Bereich der Transplantationsmedizin dar. Dabei wird ein tierisches Organ (Niere, Leber, Herz etc.) in eine andere Tierart oder in einen menschlichen Organismus implantiert. Xenotransplantation wird momentan an Tieren wie zum Beispiel Schweinen und Affen erforscht. Dabei pflanzt man dem Tier im Labor ein artfremdes Organ (also ein Organ einer anderen Tierart) ein und beobachtet die Reaktionen des Körpers auf diesen Fremdkörper.
Stell dir vor, die Xenotransplantation wäre in Deutschland legal und könnte erfolgreich bei Menschen durchgeführt werden. Nenne Folgen, die sich daraus ergeben würden.

[15] Students' answers concerning Item 2 and Item 3 have been analyzed and discussed in Study 3.

11.2.2.2. The questionnaire in English language[16]

Item 1:
Luke is six months old and possesses approximately 50 percent of the normal hearing ability. His acoustic nerve is unaffected; however; the transmission of the acoustic signal via the cochlea of the inner ear is impaired. Consequently, there is a risk that Luke's development might be affected.

In laboratory animals, such as mice and monkeys, new cochlea implants are being developed that could help people like Luke. These optical implants stimulate the acoustic nerve via light and, as a result, optical signals can be converted into acoustic ones. The implant assists the function of the inner ear improving the hearing quality of affected people.

Read the above text carefully. What ethical issues are raised and why do you think it is called a dilemma*?

> *A dilemma describes a challenging decision-making situation between two alternative courses of action, where each option has disadvantages.

Item 2:
Imagine there is to be a poll about the banning of animal testing in [Germany/Great Britain]. Would you be for or against the banning of animal testing? Choose one side and state at least three arguments for your chosen view.
(You can give arguments for the other side in Task 3)

Item 3:
There are people who have different views to you about whether animal testing is acceptable. What sorts of people might these be and what arguments might they use to back up their opinions?

Item 4:
Xenotransplantation describes the transplantation of an animal organ (e.g. a kidney, liver or heart) into a **different** species. This technique is currently being investigated using pigs and monkeys. The animal in question receives an organ from a different species and the reaction of the animal's body to this new organ is observed.

Imagine xenotransplantation becomes legal in [Germany/Great Britain] and can be successfully performed with humans **receiving** organs from a **different** species. Please state as many consequences of this as you can think of.

[16] The questionnaire has been translated and revised as part of a research visit at the University College London (Institute of Education; visiting Prof. Michael Reiss) in 2019.

11.3. Exemplary teaching material from *Expedition Erdreich*

A range of worksheets have been developed as part of the project: “Expedition Erdreich im Wissenschaftsjahr 2020” [Expedition Soil – Science Year 2020]. The worksheets have not been published yet and publication rights are reserved to the German Federal Ministry of Education and Research. The worksheet presented here was only included for reviewing purposes.

12. ACKNOWLEDGMENTS

Dissertation projects are hardly solitary endeavors and this one, without doubt, is no exception. The following section is dedicated to those who deserve a special thank you:

I wish to express my profound gratitude to Prof. Dr. Ute Harms, my supervisor, for the extraordinary support during this journey. Her thorough guidance and insightful feedback tremendously contributed to the development of my work and her open-minded trust in my ideas provided me with numerous opportunities to grow on a professional and a personal level.

I wish to sincerely thank Prof. Michael Reiss for his hospitality, support, and shared expertise during my stay at UCL. Our illuminating conversations allowed me to explore new perspectives on science education and strengthened my passion for educational research.

A heartfelt thank you to my mentors, Dr. Tim Höffler and Dr. Marc Eckhardt, for their methodological advice and mental support. As well as to Dr. Till Bruckermann, who taught me a lot about critical thinking.

A special thank you to Prof. Dr. Susanne Bögeholz, for her valuable feedback at several stages of this dissertation project and for the permission to implement her research instrument.

A bow of thankfulness to my current and former colleagues with whom I shared my time at IPN and beyond: Lara, Hanno, Julian, Birgit, Frauke, Ulli, Sebastian, Dani, Uli, Deidre, Dirk, Anje, Caro, and Alice. Isi, Danny, and Jasmin, you three deserve an extra-large bouquet of flowers! Thank you for sharing valuable insights, helpful feedback, and countless cups of coffee during the last four years.

I wish to pay my special regards to the WinnerS project group, especially the other PhD students Anneke, Eva, and Peter. Anneke, I could not feel more fortunate that this project brought us together.

My eternal gratefulness to Johanna, Marek, and Felix who assisted me in data collection and entry.

Ben, thank you for proofreading this dissertation and for the many years of precious friendship.

A wholehearted thank you to Theresa and Sascha for being by my side since high school/university. You both deserve more gratefulness than I can express with words.

Dustin, you have been such a wonderful and understanding partner during this time. Thank you for always saving me some leftover food for when I stayed up late working on this thesis.

My deepest gratitude goes to my family who, despite the geographical distance, always kept me close to their heart. Papa, thank you for introducing me to the value of science when I was little. Mama, thank you for teaching me that some things cannot be solved by scientific inquiry but by listening to your heart. Anika, you are a wonderful sister and an outstanding woman. This dissertation would not have been possible without your unconditional love.

13. DECLARATION

I hereby declare that the work presented within this dissertation, apart from the advice given by my supervisor, is my own in both format and content. All used resources have been referenced in this work. This is my first dissertation and the work has never been used in any other dissertation attempts. The dissertation complies with the standards for good scientific practice proposed by the German Research Foundation (DFG). As indicated at their respective beginnings, the three articles presented within this dissertation have been published in or submitted to scientific journals. I have not been deprived of an academic degree.

Date and location	Carola Garrecht