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Enhancing Decision-Making in STSE Education by Inducing Reflection and Self-Regulated Learning[1]

Helge Gresch[a,d], Marcus Hasselhorn[b,d], Susanne Bögeholz[c,d]

a) Center for Biology Education, University of Münster, Schlossplatz 34, 48143 Münster, Germany, helgegresch@wwu.de
b) German Institute for International Educational Research (DIPF), Schloßstraße 29, 60486 Frankfurt am Main, Germany
c) Biology Education, University of Göttingen, Waldweg 26, 37073 Göttingen, Germany
d) DFG Graduate Research Program 1195 'Understanding and Enhancing Educational Fit in Schools', University of Göttingen, Göttingen, Germany

Abstract: Thoughtful decision making to resolve socioscientific issues is central to science, technology, society, and environment (STSE) education. One approach for attaining this goal involves fostering students' decision-making processes. Thus, the present study explores whether the application of decision-making strategies, combined with reflections on the decision-making processes of others, enhances decision-making competence. In addition, this study examines whether this process is supported by elements of self-regulated learning, i.e., self-reflection regarding one's own performance and the setting of goals for subsequent tasks. A computer-based training program which involves the resolution of socioscientific issues related to sustainable development was developed in two versions (with and without elements of self-regulated learning). Its effects on decision-making competence were analyzed using a pretest-posttest-follow-up control-group design (N = 242 high school students). Decision-making competence was assessed using an open-ended questionnaire that focused on three facets: consideration of advantages and disadvantages, metadecision aspects and reflection on the decision-making processes of others. The findings suggest that students in both training groups incorporated aspects of metadecision into their statements more often than students in the control group. Furthermore, both training groups were more successful in reflecting on the decision-making processes of others. The students who received additional training in self-regulated learning showed greater benefits in terms of metadecision aspects and in reflection, and these effects remained significant two months later. Overall, our findings demonstrate that the application of decision-making strategies, combined with reflections on the decision-making processes and elements of self-regulated learning, is a fruitful approach in STSE education.

Keywords: decision-making, STSE education, socioscientific issues, education for sustainable development, self-regulated learning

In the democratic and pluralistic societies of the 21st century, all citizens should be enabled to participate in personal and collective decisions about controversial issues (Aikenhead 1985; Berkowitz & Simmons 2003; Evagorou & Osborne 2013; Solomon & Aikenhead 1994; Zeidler, Sadler, Simmons, & Howes 2005). Consequently, the science, technology, society, and environment (STSE) movement promotes the education of scientifically literate and responsible

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citizens who base their decisions on both scientific and societal considerations (Aikenhead 1985; McConnell 1982; Pedretti 2003; Pedretti & Nazir 2011; Solomon & Aikenhead 1994). Because real-world decisions frequently involve multiple fields, interdisciplinary approaches are essential to STSE education practices (Solomon & Aikenhead 1994). Environmental education requires an integration of ecological, social, economic, and political aspects (Hungerford 2010; Potter 2010; UNESCO 1978 [Tbilisi Declaration]). This interrelationship is even more strongly promoted by the education for sustainable development movement, which aims to integrate the viewpoints of different interest groups to solve various problems, such as the elimination of ecosystems, the loss of biodiversity and social injustice in a globalized world (Bourn 2005; Eilam & Trop 2011; Herremans & Reid 2002; Marcinkowski 2010; Sauvé 1996, 2005; UNCED 1992 [Agenda 21]). In consideration of this interdisciplinary nature, socioscientific issues are described as complex, open-ended, and contentious problems that lack simple and straightforward solutions (Sadler 2004). To make thoughtful decisions aimed at resolving these issues, one must not only consider scientific evidence but also the underlying values and societal norms. Science itself is not value-free, and societal contexts demand an integration of the values of the stakeholders involved (Aikenhead 1985; Eggert & Bögeholz 2006; Hodson 2003; Kolstø 2001; Ratcliffe & Grace 2003; Sauvé 2005; Zeidler & Sadler 2007; Zeidler et al. 2005). In fact, students' arguments have been shown to include value considerations (Bell & Lederman 2003; Grace & Ratcliffe 2002; Jiménez-Aleixandre & Pereiro-Muñoz 2002; Sadler & Zeidler 2004).

Thoughtful decisions and critical reflections are necessary given this complexity of evidence evolving from multiple disciplines and the need to consider underlying values. Thus, the central focus should be placed on fostering high-quality decision-making processes. This objective has been included in many science education standards and curricula worldwide (American Association for the Advancement of Science [AAAS] 1993; Kultusministerkonferenz [KMK] 2005; National Research Council [NRC] 1996; Qualifications and Curriculum Authority [QCA] 2004). In our study, we investigate how the quality of decision-making processes can be fostered through the use of decision-making strategies and reflection on their adequate use. Furthermore, we examine how this reflection process can be enhanced through elements of self-regulated learning.

Decision Making in STSE Education

Several STSE currents concern decision making, reasoning and argumentation (Pedretti & Nazir 2011; Sadler 2004). The characteristics of high- and low-quality arguments have been identified in a number of studies (Driver, Newton, & Osborne 2000; Kuhn 1991; Toulmin 1958; Zeidler 1997) and interventions designed to enhance the quality of argumentation. These interventions have been found to be successful in short-term (Venville & Dawson 2010; Zohar & Nemet 2002) and long-term studies (Osborne, Erduran, & Simon 2004). When engaged in reasoning, students often employ both rationalistic and emotive or intuitive patterns, and they frequently use heuristics (Arvai, Campbell, Baird, & Rivers 2004; Haidt 2001; Sadler & Zeidler 2005a; Zeidler 1997). However, the use of heuristics may lead to a reduction in the complexity of a socioscientific issue (Arvai et al. 2004; Payne, Bettman, & Luce 1998). Such simplification is inadequate from a normative perspective because real-world problems require a thorough analysis of the evidence and a consideration of different viewpoints.

Significant efforts have been made to assess and improve the presentation of students' viewpoints in small-group or whole-class discussions. Respective research is primarily based on the argument pattern proposed by Toulmin (1958) (i.e., the connection between data, claims, warrants, backings and rebuttals when presenting one's position). Although this approach is useful for assessing the quality of arguments, especially in small-group discussions (Erduran, Simon, & Osborne 2004), it does not reveal which decision-making strategies the individual participants used to reach their decision before the argument occurred. However, socioscientific issues often require both individual and collective decision making (Aikenhead 1985; Eggert & Bögeholz 2010; Zeidler et al. 2005). Moreover, because collective decision-making processes require individuals to agree on one final decision, individual decision making is part of the process of collective decision making (Aikenhead 1985). Therefore, understanding and reflecting on the decision-making processes of oneself and of others is vital to reaching a group compromise. Consequently, reflections on the strengths and weaknesses of decision-making processes are considered to be a useful approach to critically judging the statements of others and for enhancing one's own reasoning (Arvai et al. 2004; Baron 1994; Eggert & Bögeholz 2006, 2010; Haidt 2001; Hogan 2002; Ratcliffe & Grace 2003; Zeidler 1997).

The adequate evaluation of evidence is central to both decision making and argumentation. A major difference between these frameworks, however, is the function of the presented statements. Does a student explain overtly how he/she reached his/her decision or defend his/her viewpoint using warrants and backings after the decision has been made? The present study focuses on the individual decision-making processes that precede discourse with others. Therefore, it aims to foster decision-making competence that involves strategic considerations, i.e., the explicit use of a decision-making strategy as well as a reflection on the underlying decision-making process.

Decision-Making Strategies

Due to the complexity of many decision-making tasks associated with several options and multiple attributes, different approaches can be taken to reach a decision. Decision research has investigated the ways in which decision making actually occurs and the strategies that people apply when solving problems.

A decision-making strategy in which all advantages and disadvantages are considered in a full trade-off is called a compensatory strategy because all of the benefits and drawbacks compensate one another (Jungermann, Pfister, & Fischer 2005; Payne et al. 1998; Plous 1993). This decision-making process is described by the weighted-additive-value model, which postulates that the outcomes of some decisions are best approximated by adding the values of all of the relevant attributes that characterize the options. The underlying value hierarchy is considered by weighting the factors: more important attributes contribute more to the final result than less important attributes. A decision maker selects the option with the highest overall value because this option best fulfills the pivotal demands.

However, decision-making situations may include options that are unacceptable from the decision maker's perspective. If the characteristics of an option do not reach a minimum threshold, decision makers may exclude such options without further consideration of the advantages. Because benefits and drawbacks are not compensated, such a strategy is referred to as non-compensatory (Jungermann et al. 2005; Payne et al. 1998; Plous 1993). One example is the elimination-by-aspects rule (ibid.; Tversky 1972), in which options are excluded if they do not reach the required cut-off levels associated with the most important criterion. Subsequently, the remaining options are examined with regard to the second-most important criterion and excluded if necessary, and so forth.

These strategies are often combined so that the remaining set of options can be compared in more detail (e.g., through a complete trade-off) after an initial screening phase in which unacceptable options are excluded (Beach 1990).

Generally, different types of decision-making tasks require different decision-making strategies (Bögeholz 2007; Eggert & Bögeholz 2006; Gresch, Hasselhorn & Bögeholz 2013). Many routine decisions are best solved by applying heuristics, whereas other situations - especially complex socioscientific issues that affect various stakeholder groups - require the use of more elaborate strategies (Arvai et al. 2004; Eggert & Bögeholz 2006, 2010; Gresch et al. 2013; Hogan 2002). Regarding the framework of sustainable development, some situations suggest the use of a non-compensatory strategy, i.e., options with attributes that would lead to unsustainable development are excluded (Gresch & Bögeholz 2013). Other issues may require a complete trade-off of all options. In conclusion, a high level of decision-making competence involves strategic considerations, i.e., the explicit use of a decision-making strategy as well as a reflection on the underlying decision-making process (Eggert & Bögeholz 2006, 2010).

The decision-making process is strongly influenced by the values underlying possible courses of action. Therefore, an implicit or explicit value consideration is regarded as part of the decision-making strategy (Eggert & Bögeholz 2006; Jungermann et al. 2005; Payne et al. 1998). From a normative viewpoint, it is considered fruitful to explicitly reflect on underlying values (e.g., through a prioritization of values) to illuminate the implicit assumptions made during the process of creating judgments regarding socioscientific issues. Moreover, this is a possible means of avoiding an inappropriate reduction in complexity (Aikenhead 1985; Arvai et al. 2004; Arvai & Gregory 2003; Eilam & Trop 2011; Hodson 2003; Kolstø 2001; Sauvé 2005).

Because poor decisions are not only a consequence of missing information but also due to shortcomings and flaws in the decision-making process (Arvai et al. 2004), it is recommended that decision making be taught through the application of decision-making strategies (Eggert & Bögeholz 2006; Gresch et al. 2013) or by addressing such flaws (Arvai et al. 2004; Gresch et al. 2013; Hogan 2002; Ratcliffe & Grace 2003). Seethaler and Linn (2004), Ratcliffe (1997) and Eggert, Bögeholz, Watermann and Hasselhorn (2010) trained students to make complete trade-offs by weighing all advantages and disadvantages. Gresch et al. (2013) as well as Gresch and Bögeholz (2013) showed in a previous study that training students to apply compensatory, non-compensatory and mixed strategies enhanced their decision-making competence. Long-term effects such as an explicit prioritization of values were observed. However, the frequent use of non-compensatory strategies was unintentionally triggered through the training: although all of the decision-making tasks on the questionnaire had been designed to ensure that no option had unsustainable characteristics, students in the training groups tended to exclude options more often and thus avoided the more complex full trade-offs. Based on these findings of the pre-post analyses reported by Gresch et al. (2013), the learning program was examined in more depth. For this purpose, process-related data collected during the intervention were analyzed in an article published by Gresch and Bögeholz (2013). The use of a non-compensatory decision-making strategy was found to be slightly less cognitively demanding. This decreased demand may have led to the observed overuse of the non-compensatory strategy. Consequently, we suggest the need to reflect on the problems involved in using simplifying decision-making strategies and heuristics. Therefore, a desideratum for the present article is to combine the application of decision-making strategies with explicit reflection on flaws in reasoning, especially a hasty exclusion of options, to yield improved training in decision-making competence.

Self-Regulated Learning

Science education should prepare students for lifelong learning and thus provide them with strategies they can use for independently completing new tasks. Unfamiliar socioscientific issues challenge students to transfer such strategies to new issues. Self-regulated learning is a fruitful approach to achieving autonomy in science education (Schraw, Crippen, & Hartley 2006) because it combines the enhancement of cognitive and metacognitive strategies and motivational aspects (Boekaerts 1999; Schraw et al. 2006; Zimmerman 2000).

According to the model of self-regulated learning proposed by Zimmerman (2000), three subsequent phases of learning processes can be distinguished. Prior to processing a task, self-regulated learners set goals and select strategies that will assist them in completing the task (forethought phase). Self-monitoring and self-control ensure effective performance (performance phase). After completing the task, students self-reflect on the quality of their performance and draw conclusions for further tasks, e.g., by stating new goals (self-reflection phase). Hence, self-regulation is considered a cyclical process that demands metacognitive skills. In particular, students' explicit self-reflection with regard to their progress requires metacognitive activity to scrutinize oneself and is thus considered to be important for critical thinking (Schraw et al. 2006). We acknowledge that reasoning activities are more complex than the completion of tasks described in Zimmerman's three-phase model. However, it provides a suitably transparent framework for including elements of self-regulated learning at different points in the learning process. For example, the introduction of elements of this phase-model into regular genetics classes has been shown to be successful in improving students' knowledge of genetics and their self-regulation strategies (Eilam & Reiter 2014).

To date, the integration of aspects of self-regulated learning into research in science education has primarily focused on the effects on learning science content or improving inquiry-based activities and problem solving (Schraw et al. 2006; Eilam & Reiter 2014; Labuhn, Bögeholz & Hasselhorn 2008a, 2008b). In the context of socioscientific decision making, Gresch et al. (2013; cf. Gresch & Bögeholz 2013) integrated a task analysis as a metadecision aid into the decision-making process based on Zimmerman's theoretical framework of self-regulated learning (Zimmerman 2000). This task analysis was conducted before the application of a decision-making strategy as part of the forethought phase. Initial promising results regarding the effect of the task analysis on decision-making competence were demonstrated. Students were more aware of the flaws of intuitive reasoning. Furthermore, the integration of a task analysis to select an appropriate decision-making strategy led to a higher perceived choice during the decision-making process compared with the control group.

To conclude, the initial results demonstrate how elements of self-regulated learning can be integrated into decision-making. While elements of the forethought phase have been included, so far research has not explored how self-regulation strategies in other phases of the learning process can be incorporated into the resolution of socioscientific issues. In this study, we aimed to integrate elements of the self-reflection phase into the task of reflecting on the decision-making processes of others. After completing a task, students self-reflected on the quality of their task performance and set goals to improve their future performance.

Research Questions

This study investigates whether a reflection on the strengths and weaknesses of the decision-making processes of others improves students' decision-making competencies. Such a reflection should focus on whether a suitable decision-making strategy is used to resolve a socioscientific issue and whether flaws exist in the application of that strategy. Hence, the first hypothesis is as follows:

Hypothesis 1. Training students in the application of decision-making strategies and reflection on the quality of the decision-making processes of others enhance decision-making competence.

Science education research pertaining to decision making has rarely focused on self-regulation. However, self-regulated learning is considered worthwhile in other fields of science education because it induces metacognitive processes (Schraw et al. 2006). Therefore, the second aim of the current study is to improve this reflection on the decision-making processes of others through the use of elements of self-regulated learning after completing the task (self-reflection phase, cf. Zimmerman 2000). Thus, the second hypothesis is as follows:

Hypothesis 2. The combination of reflections on the decisions of others with self-reflection on a student's own performance and the setting of goals for future tasks enhance decision-making competence at a higher rate.

To test these hypotheses, we developed a computer-based training program to train students in applying and reflecting on the use of decision-making strategies combined with elements of self-regulated learning.

Description of Decision-Making Training

All of the participating students used a web-based training program consisting of two 45-minute sessions (see Table 1). At the beginning of the program, the framework of sustainable development - the interdisciplinary combination of ecological, social and economic facets - is introduced to provide students with the opportunity to reflect on inherent norms and personal values. Subsequently, the program randomly assigns the students to one of two training groups (TG1, TG2) or a control group (CG).

In the first session, all of the students respond to three decision-making tasks in which different courses of action must be compared before an option is selected. The main learning goal for the students in the two training groups is to be able to apply three different decision-making strategies: a compensatory strategy, a non-compensatory strategy and a combination of both strategies (see Gresch et al. 2013). Figure 1 shows an abstract version of the interface of the computer-based learning program. Furthermore, the students should learn which decision-making strategy is most appropriate in the given context. Throughout the program, students are offered text fields they can open when they need further explanations or help with the application of a decision-making strategy.

Table 1 *Structure of training program*

Training group 1	Training group 2	Control group	Contexts
Session 1[a]			
Training decision-making strategies[b] • Non-compensatory strategy • Compensatory strategy • Mixed strategy		Decision making with additional ecological information	• Decision between different measures for the protection of coral reefs • Land-use decision after brown coal mining • Choice of an aquaculture site
Session 2			
Reflecting on the decision-making processes of others based on strategic considerations		Decision making from the perspective of other stakeholders without strategic training	• Choice of a production site for a shipyard • Decision between different measures for the renaturation of a limnological ecosystem
Without elements of self-regulated learning	With elements of self-regulated learning (self-reflection on task performance and setting of goals for the next task)		

[a]Session 1 as in Gresch et al. (2013) and Gresch and Bögeholz (2013).
[b]Both training groups received the same training in session 1.

For the first issue of the first session, measures that are designed to protect a coral reef in an impoverished southern region must be compared by considering the consequences for the ecosystem, local diving schools, and individuals who depend on income from diving tourism and the financial constraints of the local community. Because some options would have a strong negative effect on ecological or social factors or would create heavy financial burdens for the local community, students are encouraged to think about the question of which options may not be sustainable and should thus be excluded. The elimination-by-aspects rule is introduced as a non-compensatory approach, and its application is facilitated by buttons that are used to systematically eliminate options if the attributes do not reach the minimum threshold established by a student.

In a second context about a land-use decision, students are required to determine which form of land use they would promote after the end of brown coal mining. Again, ecological, social and economic consequences must be considered. In this task, all of the options are considered to be equally legitimate according to the sustainability framework. Consequently, students are encouraged to use a weighted-additive-value strategy, which is one type of compensatory decision-making strategy, by converting benefits and drawbacks into positive and negative scores. Subsequently, these scores are multiplied with the weighting factor chosen by the student and followed by a summation of all of the weighted attributes to determine an overall score for each option.

For the final issue in the first session of the training program, students must choose an aquaculture site for trout (cf. Bayer, Eggert, Goldschmidt, Kiesel, Kratsch, Müller, & Winterberg 2008) by applying a mixed strategy. Sandy grounds, high temperatures in the summer and lower oxygen levels at one site are not adequate from an ecological point of view and it should be excluded. The remaining two sites then have to be compared with regard to ecological conditions, cost, location and sale options.

In all of the tasks, students are asked to reflect on the underlying values by prioritizing them or by weighting the attributes.

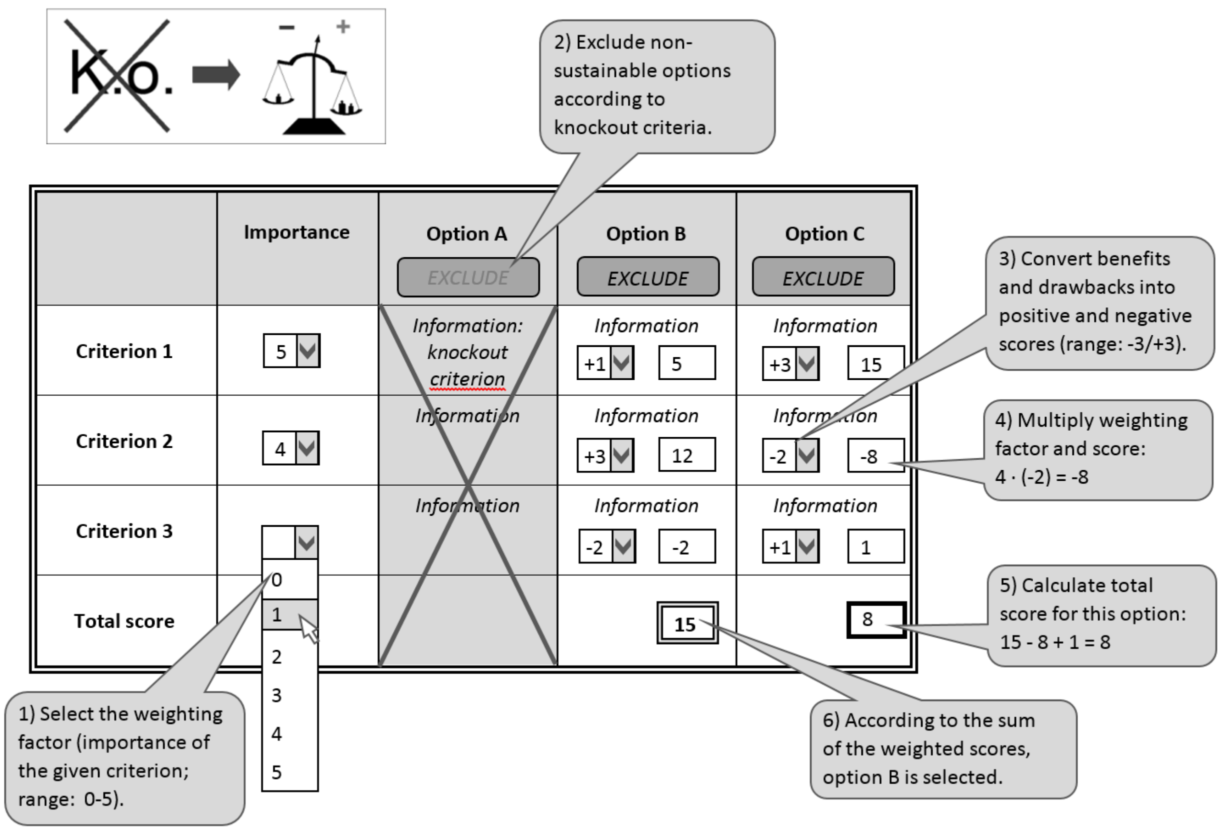

Fig. 1 Abstract version of the interface of the training program: application of a mixed decision-making strategy (non-compensatory strategy followed by compensatory strategy)

The general aim of the second session is to enable students to detect flaws in reasoning, such as the unreflected use of non-compensatory strategies, and to stimulate reflection regarding the question of which strategy is most appropriate according to the characteristics of the decision-making context. In each task, two decisions of differing quality are presented to the students in the training groups. The decision-making processes must be described and judged. One decision represents an intuitive judgment that lacks the consideration of counterevidence and other alternatives, whereas other decision makers explicitly use strategies such as non-compensatory or compensatory approaches. Students are asked to reflect on whether the exclusion of options is justifiable based on the values relevant to the decision maker or whether the exclusion of options simply represents an inadequate reduction in complexity. After reflecting on the quality of the decisions presented, students in the training groups are shown a worked example completed by an "expert" who identifies the deficits in the decisions presented. Such worked examples have been found to enhance the performance of students in problem-solving tasks (van Gog, Paas, & van Merriënboer 2006; Ward & Sweller 1990). Students in the self-regulation group (training group 2) are encouraged to compare and contrast their solutions with the completed example by marking those aspects of the exemplary solution that they have also stated. Following this self-reflection on their performance, students in training group 2 notate their goals for working on future tasks, i.e., stating aspects on which they wish to focus.

For these reflection tasks in the second session, two contexts were chosen: selection of the production site of a large enterprise that produces container ships (cf. Mühlenhoff 2009) and measures to improve a limnological ecosystem. In a river, biodiversity should be protected through enhancement of the water quality while ensuring that the local population has access to this recreational area (Eggert, Barfod-Werner & Bögeholz 2008).

Students in the control group work on the same sustainability issues and have to decide in favour of one option. However, rather than receiving training in the use of decision-making strategies, they obtain additional ecological information to inform their decisions in the first session. This control group design was chosen because purely content-based classes are the most realistic traditional approaches to dealing with socioscientific issues. Moreover, a control group with additional content knowledge is a conservative control because additional content knowledge may be more likely to improve the quality of the decision compared with less content-based information. Regarding the impact of content knowledge on argumentation quality, Sadler and Donnelly (2006) suggest in their threshold model of content knowledge transfer that a basic level of knowledge is needed for argumentation but a slightly higher amount of additional content knowledge does not strongly influence the quality of argumentation. Only a very advanced level of knowledge, such as that of students majoring in biology, may induce high-quality informal reasoning (Sadler & Zeidler 2005b). Consequently, we suggest that the additional content knowledge in the control group does not have a strong impact on the quality of the decision-making process. If it does have an effect, this should be positive, making it a conservative control. Furthermore, the additional ecological information ensures that the control group students spend the same amount of time on the issue as the students in the training groups. In the second session, the students in the control group decide from the perspectives of relevant stakeholder groups rather than reflecting on the decision-making processes of others.

Methods

Research Design

To analyze the effects of the training program on decision-making competence, we chose a pretest-posttest-follow-up control-group design. On the first day, students completed the pre-test and worked through the first session of the computer-based training program (see Table 1). On the second day which occurred within a week of the first day, students finished the program and the post-test. A follow-up test was conducted two months after the intervention. All of the students were provided with a computer and were randomly assigned to one of two training groups or to a control group when beginning to use the software.

Sample

A total of 242 students from 17 biology classes (grades 11-13, i.e., students in the last three years of high school) participated in the entire training program and the pre- and post-tests. 204 of these students also participated in the follow-up test. The schools were high-track schools (Gymnasium) or mixed-track schools (Gesamtschule) in Germany. In the latter case, low-achieving students had left school at the end of grade 10. Consequently, all of the students were high achievers. The mean age was 16.9 years, and 64 % of the students were females. Due to the randomized assignment to the treatments, the groups did not differ with regard to sex, age, biology grade, years of education or number of biology periods per week (analyses of variance). Furthermore, with regard to the pre-test results, no significant differences among the groups were found in any of the decision-making scales (analyses of variance).

Measurement of Decision-Making Competence

Decision-making competence was assessed using an open-ended questionnaire (see Eggert & Bögeholz 2010, for a detailed description of the questionnaire). During a period of 45 minutes, students completed three real-world decision-making tasks related to sustainable development; all of the tasks differed from the training tasks. In the first two tasks, students were instructed to compare and contrast possible courses of action and finally select one option among equally legitimate options. In the third task, the students reflected on the quality of the decisions made by three other individuals and offered suggestions for improvement. Each of the decisions presented in the third task – the reflection task – was based on a different decision-making strategy.

The open answers were scored with regard to three major foci (see Table 2 for the scoring rubric and Table 3 for examples of students' responses). First, concerning each student's own decision (tasks 1 and 2), the scores for eight items (representing four options per task) reflected the extent to which a student had considered the advantages and disadvantages when judging the chosen option (one item per task) and the rejected options (three items per task; see *consideration of advantages and disadvantages* in Table 2 and Table 3). Second, three metadecision aspects were examined based on six items: to what extent did students structure or plan their decision-making processes? Did they explicitly describe the aspects of the decision-making strategies that were utilized (e.g., the exclusion of options or an explicit trade-off)? Did they weight the criteria according to personal values? With regard to the weighting of criteria, the particular value considered by the students was not recorded, nor whether several values were of equal importance to the students. The only relevant aspect was whether the students' considerations regarding the weighting of criteria were stated explicitly. Third, the reflection task examined the ways in which students described the decision-making processes of others and offered suggestions for improvement (six items). Strategic descriptions and comments were considered elaborate reflections (Eggert & Bögeholz 2010). Because these items are polytomous with different maximum scores, they were equi-weighted to ensure that each item contributed equally to the scale.

Table 2 *Scoring guide of the decision-making questionnaire*

Item description	Score 0	Score 1	Score 2	Score 3
		Consideration of advantages and disadvantages		
Chosen and rejected options [a]	Does not state anything.	States either positive or negative aspects.	States both positive and negative aspects.	
		Metadecision aspects		
Structuring and planning of decision-making process [b]	Does not explicitly structure or plan decision.	Structures and plans decision explicitly.		
Description of aspects of the underlying decision-making strategy [b]	Does not explicitly describe strategic aspects.	Describes strategic aspects explicitly.		
Weighting of criteria according to personal values [b]	Does not explicitly weight criteria.	Weights criteria explicitly.		
		Reflection		
Description of non-compensatory decision making [c]	No reference to strategy.	Reference to one aspect of strategy.	Reference to two aspects of strategy.	Reference to at least three aspects of strategy.
Description of compensatory decision making [c]	No reference to strategy.	Reference to one aspect of strategy.	Reference to two aspects of strategy.	Reference to at least three aspects of strategy.
Description of intuitive decision making [c]	No reference to strategy.	Reference to one aspect of strategy.	Reference to at least two aspects of strategy.	
Suggestions for improvement of non-compensatory decision making [c]	No suggestions on strategic level.	Suggestions on strategic level with one aspect.	Suggestions on strategic level with at least two aspects.	
Suggestions for improvement of compensatory decision making [c]	No suggestions on strategic level.	Suggestions on strategic level with one aspect.	Suggestions on strategic level with at least two aspects.	
Suggestions for improvement of intuitive decision making [c]	No suggestions on strategic level.	Suggestions on strategic level with one aspect.	Suggestions on strategic level with at least two aspects.	

Note. Based on Eggert and Bögeholz (2010) and the results from the qualitative content analysis.
[a]8 items. [b]2 items. [c]1 item.

Table 3 *Examples of the students' responses in the decision-making questionnaire*

Item description	Example
Consideration of advantages and disadvantages	
Chosen and rejected options	"The first method is not suitable because this could still lead to overfishing. The supply of fish in the shops is very high, but the fish would be extinct after several years." (*rejected option; both advantages and disadvantages are considered*)
Metadecision aspects	
Structuring and planning of decision-making process	"In this case, I will also sort out according to knockout criteria." "Then, I will have a look at the second-most important criterion."
Description of aspects of the underlying decision-making strategy	"Option 1 (*pesticides*) is excluded because it may irritate the eyes of rabbits and because it doesn't work 100 %." (*non-compensatory decision making*) "You should put up with the resulting costs for the love of the environment." (*compensatory decision making*)
Weighting of criteria according to personal values	"Furthermore, you have to decide, what's more important. And in this case, I assume that the fish, which have to be regenerated through this measure, have priority." "I will concentrate on the criteria threat (*to the fish population*) and jobs. I consider both criteria to be very important."

Table 3 (continued) *Examples of the students' responses in the decision-making questionnaire*

Item description	Example
	Reflection
Description of non-compensatory decision making	"Paul decides directly against something if an important point does not match with his ideas."
Description of compensatory decision making	"Martina weighs advantages and disadvantages of the respective options. She assigns a factor of importance to each criterion and multiplies it with the number of points she gives for each option."
Description of intuitive decision making	"He decides according to instinct and merely justifies later." "Moreover, he does not mention negative aspects of other products."
Suggestions for improvement of non-compensatory decision making	"Claudia should not only sort out options due to poor criteria but also look at the positive aspects."
Suggestions for improvement of compensatory decision making	"Martina should again look at what's most important for her and see whether the points for a win come from a more important or less important criterion."
Suggestions for improvement of intuitive decision making	"I would advise her to think about criteria that are important or not important to her – as Claudia and Jan did – and then orientate herself by these criteria to make a trade-off." "She should also take other criteria into account and not restrict herself to one thing."

Note. Scoring rubric based on Eggert and Bögeholz (2010) and the results from the qualitative content analysis.

The scoring of the metadecision aspects of the students' answers was not originally included in the rubric suggested by Eggert and Bögeholz (2010), with the exception of the item "weighting criteria according to personal values." However, Means and Voss (1996) suggest that the inclusion of metastatements is one element of strong informal reasoning. Because the intervention study focused on such strategic considerations during the decision-making process, the extension of the scoring rubric was valuable to describe the effects of the training in more detail. To determine which metadecision aspects were integrated by students, we developed categories in a qualitative content analysis using a deductive-inductive approach (Mayring 2008). Thus, all of the categories were derived from decision-making theories (Jungermann et al. 2005; Payne et al. 1998), the works of Means and Voss (1996) and Eggert and Bögeholz (2006, 2010). These categories were then refined according to the investigated data. For this development of additional scoring categories, approximately 25 % of all pre- and post-tests (n = 100) were analyzed. A maximal variety of answers was sought by including both the training groups and the control group to represent different levels of competence before and after the training. The new scoring rubric (with examples and scoring definitions) was then used for the analysis of all questionnaires.

For motivational reasons, different contexts were used in the pre-test compared with the post-test and the follow-up test. Although the structure and the scoring rubric were identical at all times of measurement, the difficulty of the questionnaires may have varied. Hence, all of the final scores of the scales were *z*-standardized according to the mean and standard deviation of the control group. These steps were conducted separately for each measurement time to generate an identical baseline for comparison. These *z*-standardized values were used to conduct analyses of covariance to compare the training groups with the control group.

For all of the analyses, the missing data were list wise excluded.

The quality of the questionnaire with respect to its validity and reliability had been analyzed in detail by Eggert and Bögeholz (2010) and it was satisfying. In the study presented here, the reliability (Cronbach's alpha) of the dependent variables was as follows: consideration of advantages and disadvantages: .833 (post-test) / .798 (follow-up-test); reflection: .692 (post-test) / .572 (follow-up-test)). The reliability was mostly satisfactory considering the heterogeneity of the measured constructs. However, the internal consistency of the reflection scale was only moderate in the follow-up-test. The three metadecision aspects (structuring and planning of the decision-making process, description of aspects of the underlying decision-making strategy, weighting of criteria according to personal values) were analyzed on the item level because these aspects are too heterogeneous to be evaluated in one scale. Analysis of these aspects on the item level is also beneficial because it is possible to demonstrate separately detailed information on performance with regard to these distinct facets of decision-making.

Half of the questionnaires were recoded by a specially trained second rater. The interrater agreement (percentage of agreement) was substantial: consideration of advantages and disadvantages: 89 %; metadecision aspects: 90 %; and reflection: 83 %. After determining the interrater agreement, all of the differing scores were discussed by the two raters who then agreed on a final score.

Results

Two hypotheses are examined in the present study. For each hypothesis, results regarding three facets of decision-making competence are presented: consideration of advantages and disadvantages, metadecision aspects and reflection (see Table 2 for the scoring rubric and Table 3 for examples of students' responses).

Hypothesis 1: Training students in the application of decision-making strategies and reflection on the quality of the decision-making processes of others enhances decision-making competence.

To evaluate this hypothesis, training group 1 (TG1) is contrasted with the control group (CG).

Consideration of Advantages and Disadvantages

Regarding the students' own decisions, the analysis of covariance of the post-test and follow-up results showed that the intervention had no effect on the number of integrated advantages and disadvantages when controlling for the number of advantages and disadvantages described in the pre-test.

Metadecision Aspects

However, the groups differed with respect to whether metadecision aspects were included in the decisions (see Figure 2). For the analysis of these items, the scores from both decision-making tasks were summed for each category. The progression from pre-test to post-test was characterized by distinguishing between students who had improved their scores and those who had not. Chi-square analyses revealed that TG1 demonstrated more frequent improvements than CG: students from TG1 planned and structured their decision-making processes more frequently ($\chi^2 = 5.1$, $df = 1$, $p < .05$) and explicitly described the strategic aspects of the underlying decision-making strategy ($\chi^2 = 7.8$, $df = 1$, $p < .01$). Furthermore, the criteria were more often weighted according to personal values ($\chi^2 = 19.8$, $df = 1$, $p < .001$).

The long-term progression was significant in the follow-up-test for the description of the aspects of the underlying strategy for TG1 ($\chi^2 = 5.6$, $df = 1$, $p < .05$) but not for the other two metadecision aspects.

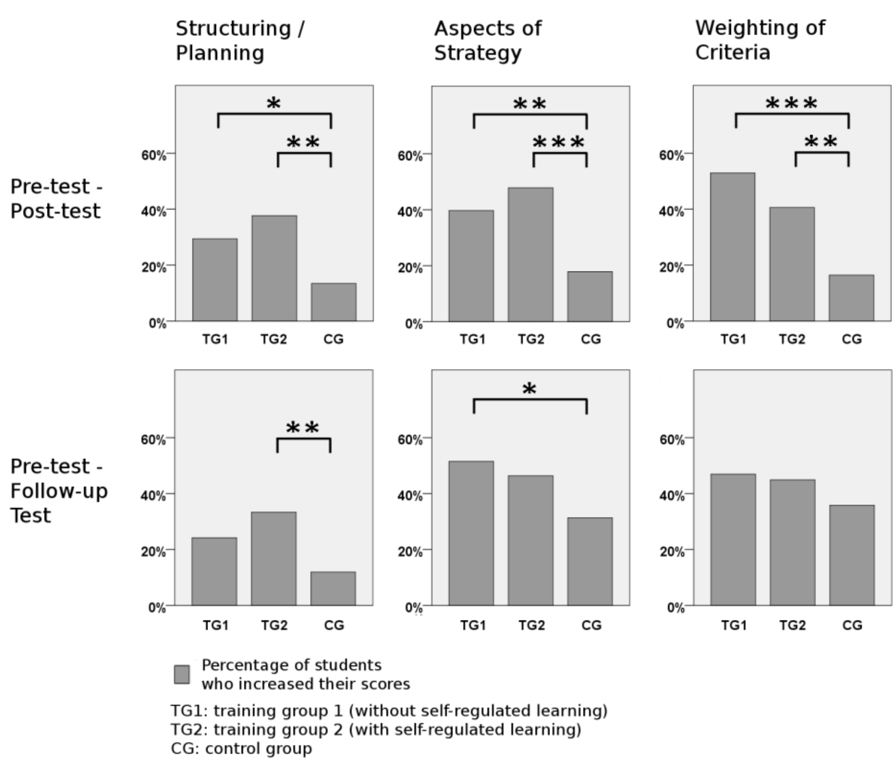

Fig. 2. Metadecision in decision-making task: percentage of students who increased their scores. *$p < .05$. **$p < .01$ ***$p < .001$.

Reflection

Training effects on the performance of students as they reflect on the decision-making processes of others were investigated by conducting pairwise analyses of covariance of the post-test scores while controlling for pre-test scores (see Figure 3). In the comparisons of TG1 with CG, TG1 was found to be significantly superior ($F_{(1,96)} = 11.810$, $p < .001$, *partial* $\eta^2 = .110$).

The follow-up analysis did not reveal a significant effect when comparing TG1 and CG ($F_{(1,96)} = 2.950$, $p = .089$, *partial* $\eta^2 = .030$).

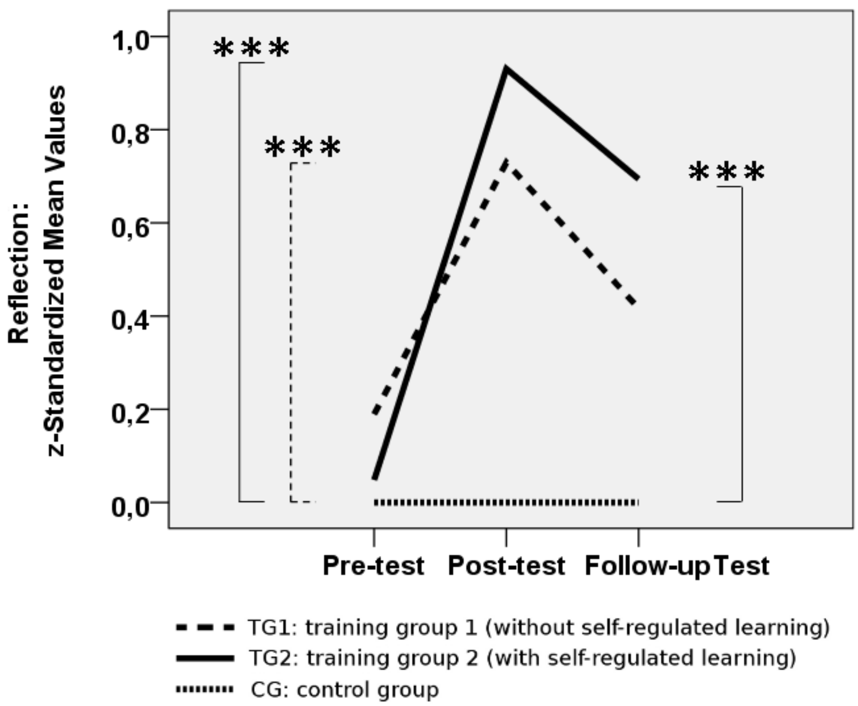

Fig. 3. Reflection: mean values (relative to z-standardized control group)
$^*p < .05$. $^{**}p < .01$ $^{***}p < .001$.

In conclusion, the students in TG1, who learned to apply decision-making strategies and reflected on the decision-making processes of others, were significantly superior to CG with regard to metadecision aspects and the reflection scale of the questionnaire. However, most of these effects did not last until the follow-up test two months later.

Hypothesis 2: The combination of reflections on the decisions of others with self-reflection on a student's own performance and the setting of goals for future tasks enhance decision-making competence at a higher rate.

To evaluate hypothesis 2, training group 2 is contrasted with the control group and training group 1.

Consideration of Advantages and Disadvantages

In the students' own decisions, the number of integrated advantages and disadvantages did not differ significantly between TG2 and CG.

Metadecision Aspects

Similarly to TG1, the students in TG2 included more metadecision aspects into their decision than the CG (see Figure 2). Again, chi-square analyses regarding the improvement from the pre-test to the post-test are presented. The students from TG2 planned and structured their decision-making processes more frequently ($\chi^2 = 10.5$, $df = 1$, $p < .01$) and explicitly described the strategic aspects of the underlying decision-making strategy ($\chi^2 = 13.7$, $df = 1$, $p < .001$). Furthermore, the criteria were more often weighted according to personal values ($\chi^2 = 9.7$, $df = 1$, $p < .01$). However, students from TG1 and TG2 did not differ significantly from one another.

The long-term progression was significant for the structuring and planning of the decision-making task for TG2 compared with CG ($\chi^2 = 8.8$, $df = 1$, $p < .01$).

Reflection

In the same way as for hypothesis 1, the training effects on the students' performance as they reflected on the decision-making processes of others were evaluated through pairwise analyses of covariance of the post-test scores while controlling for pre-test scores (see Figure 3). In the comparison with CG, TG2 was found to be significantly superior ($F_{(1,105)} = 22.960$, $p < .001$, *partial* $\eta^2 = .179$).

Contrary to TG1, which did not yield significantly higher scores on the reflection scale in the follow-up-test, TG2 was found to be significantly superior to the CG two months after the training ($F_{(1,105)} = 12.248$, $p < .001$, *partial* $\eta^2 = .104$).

In addition to these results on the scale level, the analyses of two items from this scale will be presented because the recognition of intuitive judgments and suggestions for improvement are of particular importance. Looking at the results in detail, chi-square analyses revealed significantly more improvement for TG2 in the post-test compared with CG (see Figure 4): descriptions of the intuitive statements ($\chi^2 = 9.5$, $df = 1$, $p < .01$); offering suggestions for improvement ($\chi^2 = 6.7$, $df = 1$, $p < .01$). Examining differences between the training groups, we found that the group that had received the self-regulation training (TG2) improved its score for the description of the intuitive judgments more frequently than TG1 ($\chi^2 = 4.1$, $df = 1$, $p < .05$).

On the follow-up test, the performance difference observed between TG2 and the CG remained stable in the two months following the intervention (description of intuitive judgment: $\chi^2 = 4.0$, $df = 1$, $p < .05$; suggestions for improvement: $\chi^2 = 7.5$, $df = 1$, $p < .01$). In the comparisons of TG1 and TG2, the results on the follow-up test were similar to the post-test: TG2 obtained significantly higher scores than TG1 regarding the description of intuitive judgments ($\chi^2 = 6.5$, $df = 1$, $p < .05$).

In conclusion, students in TG2, who were additionally stimulated to use self-regulation strategies, included more metadecision aspects than CG students and yielded higher scores on the reflection scale. In contrast to TG1, many of these effects remained stable in TG2 and were still observed in the follow-up-test two months after the training.

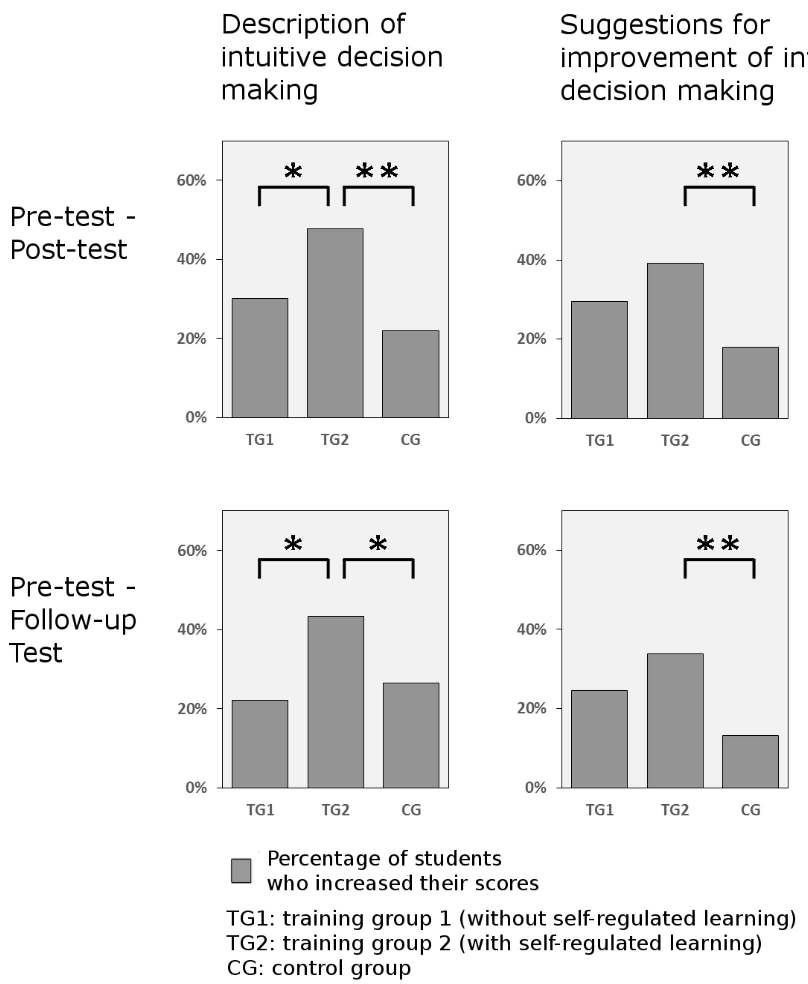

Fig. 4. Reflection: percentage of students who increased their scores.
*p < .05. **p < .01 ***p < .001.

Discussion and Conclusions

The first hypothesis of the presented study suggests that students' decision-making competence is enhanced by training in the application of decision-making strategies and the reflection on the quality of the decision-making processes of others. The analysis of students' decisions revealed that students in the training groups improved more in terms of including metadecision aspects: students in these groups structured and planned their decision-making processes more frequently than students in the control group, and they explicitly described aspects of their decision-making strategies. According to Means and Voss (1996), this use of metastatements is indicative of high-quality reasoning. Furthermore, the criteria that were relevant to the socioscientific issues were more frequently weighted according to personal values after the training. Hence, the program was successful in triggering the consideration of underlying values, which is beneficial for the resolution of socioscientific issues (Aikenhead 1985; Hodson 2003; Kolstø 2001).

The amount of evidence in terms of the number of advantages and disadvantages of possible courses of action that students considered remained constant as a result of the training. This outcome shows that a central aim of this intervention was achieved. In an earlier intervention study, Gresch et al. (2013) found that students who were trained in decision-making strategies *without* subsequent reflections on the shortcomings and flaws of decision-making processes tended to include less evidence than the control group. This outcome indicated an overuse of the non-compensatory decision-making strategy. However, in the present study, the students' decisions became more transparent through metastatements on a strategic level, without reducing the amount of evidence presented. Hence, the reflection on the hasty exclusion of options in the second session of the training program prevented students from overusing non-compensatory strategies that could reduce the complexity of the decision-making task.

Regarding the reflection section of the questionnaire in which students judged the decision-making processes of other people, the training effect was significant when the training groups were compared with the control group. This result indicates that the students in the training groups were more likely to describe decisions on a level that involved the strategic aspects of the decision-making process.

Furthermore, the suggestions regarding the improvement of the decisions included strategic considerations more frequently. Compared with the results of the earlier study (Gresch et al. 2013), which focused on the application of decision-making strategies without an explicit reflection on the quality of the decision-making process, this training was more effective due to the reflection tasks in the course of the program.

The second focus of the presented study is the hypothesis that self-regulation activities, i.e., self-reflecting on one's own performance and setting goals for future tasks, foster decision-making competence at a higher rate. When discriminating between the treatments with and without self-regulated learning, the authors found a significant difference for the reflections on intuitive judgments. This result is noteworthy because the recognition that intuitive judgments lack the consideration of evidence and alternatives is important when judging the quality of other people's arguments (Arvai et al. 2004; Baron 1994; Eggert & Bögeholz 2006; Haidt 2001).

Regarding other aspects of decision-making competence, the group that received self-regulation training revealed larger effect sizes than the group that did not receive this training. More importantly, key aspects such as the structuring and planning of decision-making tasks and the reflection of the decisions of others were still empirically observable two months after the training. These long-term effects were not significant for training group 1, which did not receive training in self-regulated learning. Hence, the self-reflection on task performance and the setting of goals for future tasks were shown to be beneficial for gaining decision-making competence with regard to metadecision aspects and reflection. These findings show that self-regulated learning activities are not only valuable in enhancing problem-solving or knowledge acquisition (Schraw et al. 2004; Labuhn et al. 2008a) but also in fostering decision making. However, one limitation of the training realized in this study is that only two facets of self-regulated learning were included, i.e., self-reflection on the students' own performance and goal setting for future tasks. Both activities belong to the self-reflection phase according to Zimmerman's model of self-regulated learning. Elements of other phases in the learning process, such as the forethought phase and the performance phase, were not incorporated. The reason was to investigate the influence of these elements of the self-reflection phase in isolation. Gresch et al. (2013) and Gresch and Bögeholz (2013) showed that a task analysis as part of the forethought phase may also contribute to enhance decision-making competence, particularly to detect flaws in intuitive reasoning. Science education practice, however, should not look at these phases in isolation but rather integrate aspects of all of these phases of the self-regulated learning cycle into decision-making.

Regarding the design of the study, we assume that a control group with additional ecological information is a conservative control because additional content knowledge may be more likely to improve the quality of the decision relative to less content-based information. Yet, a small amount of additional content knowledge is unlikely to have a strong impact on the quality of the decision-making process. A limitation regarding the design is that the students in the control group did not learn to apply decision-making strategies. A further control group that is trained in decision-making strategies *without* a subsequent reflection on the decision-making processes of others would have allowed for evaluating the effects of the reflection on decision-making competence in isolation.

Regarding method, this study is limited by the moderate internal consistency (Cronbach's alpha) of the reflection scale for the follow-up test.

Therefore, effects should be evaluated with caution yet it should be noted that this construct is complex and heterogeneous: decisions of three people were presented as solutions to the socioscientific issue, and each used different strategies to arrive at his/her decision. However, these aspects still belonged to the same construct from a theoretical point of view because they all represented important facets of an adequate reflection (Eggert & Bögeholz 2006, 2010).

To evaluate the results, the structure of the training program and the questionnaire should be contrasted. In the course of the training, three decision-making strategies were applied. Here, only the compensatory strategy required a full trade-off between all of the benefits and drawbacks, whereas the non-compensatory or mixed strategy allowed for the exclusion of options if courses of action were considered unsustainable with regard to ecological, economic or social consequences. Unlike the training program, the questionnaire was constructed in a way that each of the decision-making tasks required a full trade-off because no option was considered to be unsustainable according to the framework of sustainable development. Therefore, future research should focus on the development of test instruments designed to cover a wide range of decision-making situations and requiring the use of different decision-making strategies. At the same time, results are quite promising considering the differences between the intervention and the questionnaire.

In addition to the training program effects, the present study also delivered an extension of the scoring rubric by adding metadecision aspects (see Table 2 and Table 3). Metastatements are considered to be a component of high-quality reasoning (Means & Voss 1996) and were coded with substantial interrater agreement.

Caution should be given regarding transferability to science education practice because the intervention was computer-based and not conducted by trained teachers. Whether a similar effect on decision-making competence can be achieved through a classroom-based intervention remains to be tested. Nevertheless, the intervention took place during regular biology classes to ensure as much validity as possible. On the other hand, this design was advantageous because the students could be randomly assigned to one of the three treatment conditions. It was thus possible to control for effects of class, teacher or school on performance.

In summary, the combination of decision-making strategies and reflections on reasoning flaws, enriched with elements of self-regulated learning, provides a fruitful approach to enhancing students' decision-making competence and ensuring long-term effects.

Implications for STSE Education

The present study demonstrates that a short intervention based on decision-making strategies is beneficial in enhancing the quality of students' decisions in the long term. This outcome is comparable to the results of Zohar and Nemet (2002), who showed that short-term argumentation training improved the quality of students' arguments. Consequently, these findings support the claim that decision making can be fostered in a short period of time. Nevertheless, we claim that decision-making and argumentation training should not be an addendum to science and environmental education but rather, such training should be a central part of this education.

Similarly, self-regulated learning needs long-term integration into science classes to develop. Eilam and Reiter (2014) investigated the effects of a year-long intervention that included elements of all three phases of the self-regulated learning cycle (Zimmerman 2000). Findings from our study and from Gresch et al. (2013, cf. Gresch & Bögeholz 2013) may be used to investigate self-regulated learning in long-term interventions if the entire three-phase model suggested by Zimmerman (2000) is integrated into socioscientific issue-based classes.

One implication for STSE education concerns the necessity of reflecting on the strengths and weaknesses of the decision-making strategies used by other people. Therefore, teachers should address the pitfalls of an inappropriate reduction of task complexity through an unjustified use of a non-compensatory strategy. The present study showed that strategic considerations regarding shortcomings and flaws in reasoning constitute a suitable approach to reaching this goal. Particularly in the area of education for sustainable development, it is vital that students be able to distinguish between decisions that involve unsustainable courses of action (and thus require the use of a non-compensatory strategy) and decisions that require full trade-offs. Although this study focused on education for sustainable development, decision-making strategies are possibly also applicable and useful in other STSE contexts.

Because the process of reflecting on the use of decision-making strategies requires metacognitive skills that develop as students mature (Labuhn et al. 2008b), the influence of this development should also be investigated. In the study presented here, upper secondary school students were trained. Which aspects of this strategic training can be transferred to younger students? At what age can students learn to distinguish between several possible decision-making strategies and reflect on their adequate application? Which methods are suitable for encouraging effective decision making in different age groups?

In our study, each student was individually trained. Therefore, future research should focus on two aspects to integrate individual and collective decision making. First, intervention studies that involve training teachers in the application of different decision-making strategies and reflections on flaws in decision-making processes are vital to the establishment of classroom activities as alternatives to computer-based programs. Eggert et al. (2010), for example, trained seventh-graders to apply a compensatory strategy in cooperative learning settings. Second, the relationship between individual and collective decision making should be illuminated: how can teachers organize science classes to give room for individual decisions as well as group or whole-class discussions? Classroom discussions should also address which decision-making strategy is best suited for specific types of socioscientific issues related to sustainable development. Moreover, the findings from this study suggest that the students should reflect on the quality of decisions. In what way can teachers encourage students to give feedback on the decision-making processes of other participants in the discussion?

The integration of educational psychological theories such as self-regulated learning into science education presents quite a challenge. In the field of STSE education, this study presents initial promising results regarding how decision making can be enhanced through a reflection on decision-making processes and elements of self-regulated learning.

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