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Using the socioscientific issue approach to foster secondary students' argumentation skills, science self-efficacy beliefs and science interest

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ABSTRACT

Socio-scientific issues (SSI) are open-ended social problems with substantive connections to science. They represent the kind of situations in which many people must decide between different perspectives and decisions. Therefore, using these issues in formal science education provides an ideal approach for promoting scientific literacy and moral education. We designed a series of seven lessons that aimed to build relevant skills in young people so that they can participate responsibly in pandemic response measures. In the study, three classes with 49 Grade 9 students formed the basis for a mixed-methods analysis. We measured knowledge, attitudes, and argumentation skills. Science interest and self-efficacy beliefs increased, although students showed no growth on average in the knowledge test. Unexpectedly, no significant development in moral and value attitudes was detected. However, socioscientific accountability turned out to be helpful in explaining differences in interest and efficacy beliefs. Argumentation skills seemed dependent on the students' socioeconomic status (SES) only. Various proposals for further studies on the hitherto little-studied interactions between variables for explaining SSI understanding are discussed.

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Socio-scientific issues; science instruction; argumentation; moral attitudes

Introduction

Most young people in Switzerland readily complied with measures to contain the pandemic but were not consulted, even though they were affected, for example, by school closures, whereas adults were able to participate in two polls about COVID-19 measures. Schmid-Federer (2022) calls for young people to have more decision-making rights and for the voting age to be lowered to 16. To be able to discuss such measures, young people need argumentation and critical thinking skills (Billingsley et al., 2021; Tyrrell & Calinger, 2020), along with substantive scientific knowledge and a good understanding of scientific procedures. The media provides information about science and what scientists do to understand the universe, but students need to be able to interpret this information (Wong et al., 2011).

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We conducted a model lesson series that showed secondary school teachers how to build the appropriate competencies in young people so that they can participate responsibly in pandemic responses. This lesson series is based on the socio-scientific issue (SSI) approach (Presley et al., 2013). A socioscientific issue poses a contentious dilemma, in the form of an ill-structured, open-ended, and complex problem. We adapted the SSI instructional model by Friedrichsen et al. (2016). The content of SSI is usually controversial and characterised by dilemmas that can be discussed by learners from different perspectives. As such, these dilemmas are usually inextricably linked to morality and ethics (Yap, 2014). Zeidler (2014) emphasises that responsible thinking is ethically imperative because of the social impact of our actions. Science education aims, among other things, to prepare students to discuss socially significant issues (Atabey & Topçu, 2024), thereby fostering their decision and argumentation skills (Venville & Dawson, 2010). Therefore, current science education must also inculcate respect and compassion for human life and nature in general. In this sense, science education is often directly linked to the social-emotional goals of character education (Lee et al., 2013). Morals, values and ethics could therefore be usefully integrated into science education (Berkowitz & Simmons, 2003). According to Atabey and Topçu (2024) few studies have assessed SSI lessons with regard to the development of character and values, and more research is needed.

The objectives of our research project for the participating students were (1) promoting young people's understanding of responsible social action and why this behaviour makes sense during a pandemic, (2) promoting young people's understanding of behavioural measures that might be used against the pandemic and capacity to talk about them, and (3) strengthening young people's competence at informing themselves by means of the media. Our research question in this regard was to what extent secondary school students' social and moral compassion, and socioscientific accountability would explain the development of the students' argumentation skills, interest, and self-efficacy beliefs. In addition, we looked at the students' growth in knowledge and attitudes towards societal issues. Few empirical studies quantitatively analyse the implementation of SSI in secondary schools in Switzerland or Europe overall (Atabey & Topçu, 2024; Çalik & Wiyarsi, 2024; Viehmann et al., 2024).

Theoretical background

SSIs are open-ended social problems with substantive connections to science (e.g. climate change, gene therapy, or nuclear power). Use of these issues in formal science education provides an ideal approach for promoting scientific literacy at the secondary school level (Presley et al., 2013). The research community distinguishes two visions of scientific literacy (Roberts, 2007): the first limited in scope to the 'purely' scientific, and the second encompassing 'real' situations that are scientific in nature but are influenced by other factors, such as social, political, and ethical issues. The latter addresses SSI. This vision of scientific literacy focuses on the decision-making and negotiation of scientific issues for all citizens, not just those who aspire to become scientists (Presley et al., 2013). Framing science instruction using SSI as context enables students to learn science by developing an awareness of the interrelationship between social, political, and scientific perspectives while learning important science content and practices such as reasoning, argumentation, and decision-making (Jiménez-Aleixandre & Erduran, 2007).

Studies have shown that applying SSI in the science classroom can improve students' argumentation skills (Dawson & Carson, 2020; Venville & Dawson, 2010).

The SSI instruction model developed by Friedrichsen et al. (2016) features a series of science lessons designed around a compelling societal issue, in which the students are meant to acquire science knowledge and practices as a basis for negotiating societal problems. It is recommended that media be used to connect classroom activities to the 'real world' (Presley et al., 2013). Hence, the students need digital skills to understand the constructed nature of media and become better prepared to find, interpret, and evaluate the messages delivered through the media (Klosterman et al., 2012; Maia et al., 2021). The SSI model aims also to have students use higher-order practices (e.g. reasoning, argumentation, decision-making and/or position-taking). At the end of the lesson sequence, a culminating experience gives learners opportunities to integrate what they have learned with their prior knowledge and in turn to relate this knowledge to the issue. These culminating experiences may take multiple forms, including role-play and debate (Presley et al., 2013). Such student-centred learning enables students to connect their emotions to the SSI, which is an important feature of learning success (Zeidler, 2021). Ritchie and Tomas (2013) report that writing short stories about an SSI stimulates students' interest and elicits positive emotional responses, while their conceptual understanding develops and their attitudes towards science become more favourable.

Billingsley et al. (2021) conducted two exploratory workshops with secondary school students on COVID-19 and science for advancing students' epidemic insights. They show that the use of science in a real-world problem contributes to students' capacities to think critically about the nature, application, and communication of knowledge. The research group noticed that students' epidemic insights before the workshops were underdeveloped, so the project supported opportunities to strengthen understanding. Discussions in which students must think about how science informs decision-making are important to their learning. Similarly, Mei (2019) has shown that a lesson series with an SSI approach can foster lower secondary school students' critical thinking with respect to making inquiries into SSIs, discussing SSIs from multiple perspectives and using credible sources to support their arguments.

Teaching SSIs is not without obstacles, as Owens et al. (2021) have noted in a case study: the teaching and learning of the issue should be contextualised to the students' experiences. Crucially, students should be taught to value the multiplicity of perspectives that exist regarding an issue. Furthermore, students should be encouraged not to blindly trust information sources on the subject and to discuss them critically. For the issue we chose, one needs to be aware that students' emotions during the COVID-19 pandemic have shown increased levels of perceived stress and anger (Shanahan et al., 2020). Therefore, negative emotional reactions could also arise during SSI lessons depending on the issue.

When one thinks responsibly about scientific issues, sooner or later ethical questions will arise, as our scientific actions can ultimately have far-reaching effects on society. Responsible thinking therefore requires reflective judgement based on scientific knowledge and ethical principles (Atabey & Topçu, 2024; Fowler et al., 2009). Individuals therefore need guidance in recognising universal moral principles that should guide their decisions (Zeidler & Sadler, 2007). Lee et al. (2013) developed an instrument to measure the students' character and moral development and applied it in a study with one teacher and 132 secondary school students in Korea. In seven lessons the students dealt with the SSI genetic modification. Over time the students demonstrated growth in social and moral compassion as well as in socioscientific accountability. Accountability means that one is answerable for the outcomes of a particular decision or course of action. Qualitative data indicate that students seem to have found it difficult, at least initially, to consider multiple perspectives and thereby developing their perspectives in this regard. A study in one school by Powell et al. (2021) with five classes on animal cloning replicates the results of Lee et al. (2013). The students showed significant social and moral development over time. Students recognised the moral context in which animal cloning should be considered. The result for willingness to act was ambiguous and difficult to interpret: no effect was seen in the quantitative data, while in the qualitative data, a willingness to raise money to bring awareness to the issue via media turned up, which is some kind of willingness to act. What remains open in the research of Powell et al. (2021) is the question of how the constructs interacted and whether they helped to explain differences between students in knowledge or interest.

Purpose of the present study

In our exploratory study, we intended to test the practicality of our lesson design and the efficiency of the research instruments. We chose the coronavirus as the topic, as all the students had had their own experiences, and the topic of the immune system is well anchored in the curriculum. This choice also allows us to dock onto existing research literature (Billingsley et al., 2021; Çalik, 2021; Tyrrell & Calinger, 2020). Furthermore, while Lee et al. (2013) report the benefits of SSI for the development of value and moral attitudes, the relevance of these attitudes for explaining other characteristics of students' SSI understanding as shown in our research model (Figure 1), such as knowledge or argumentation skills, is not yet well researched. Figure 1 depicts those features of SSI understanding we intend to explore in our research.

This leads to the following questions:

1. How do knowledge, moral attitudes, and interest towards COVID-19 as an SSI develop during the lesson series?

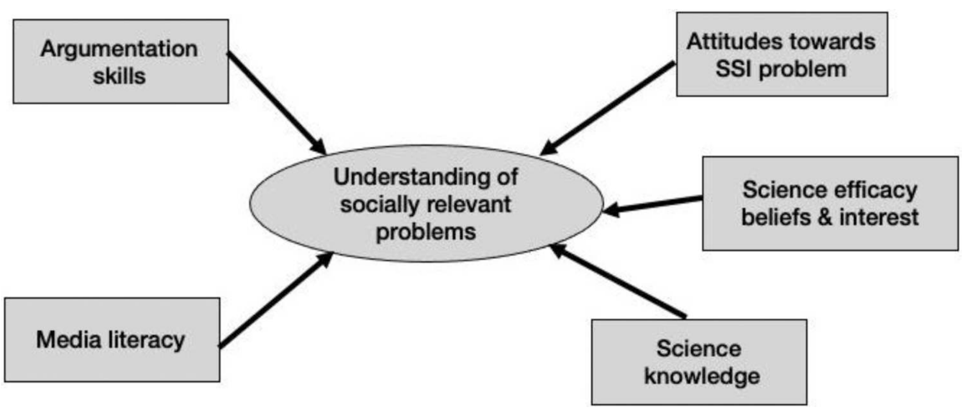

Figure 1. Research model for explaining students' understanding of socially relevant problems.

2. How do knowledge, media literacy, moral attitudes, and interest interact towards the aim of increasing students' understanding of an SSI by the end of the lesson series? Specifically, we pose these questions:
   2.1. What factors of SSI understanding explain students' knowledge?
   2.2. What factors of SSI understanding explain students' efficacy beliefs and interest?
   2.3. What factors of SSI understanding explain students' argumentation skills?

Method

Research design

Our mixed-method study had a convergent parallel design. It included a quantitative pre/post survey with additional qualitative data gathered during the final lessons (see Table 1). The seven lessons were taught during the regular biology classes at two schools. To win over the teachers, we had to limit the time, so each series was completed within two to three weeks, during the year 2023 at one school and during 2024 at the other. Seven lessons is a little shorter than in the study by Friedrichsen et al. (2016) but is still about twice as long as a teacher in Switzerland would normally spend on the topic. Apart from the pre/post questionnaire and knowledge test, a video recording of the discussion activity, when students exchanged arguments based on their acquired science knowledge with respect to the societal issue (the pandemic) was produced. The discussion as culminating activity was supported by a poster with behavioural advice for the population (Mei, 2019). As instructional method for this activity cooperative learning was chosen, and the class was divided into small groups, as suggested by Solli et al. (2019). We used the Grade 8 textbook *NaTech* (science and engineering) as instructional material for Lessons 1–5. The textbook dealt with the immune system (viruses, the body's defence system, vaccinations).

As already mentioned, we have modelled the design of the lesson series on Friedrichsen et al. (2016). The model consists of three steps: the focal issue, social connections and media, and a culminating experience. Our first step was more intensive and less student-oriented than that in the study by Powell et al. (2021). We felt that this rather complex

Table 1. Lesson design and research instruments.

Lesson	Activities	Research/Pedagogical Instruments; T = Time
1	Pupils build up an emotional connection (commitment) to the topic and reflect on the social and private significance of the pandemic. Images and news from the media on the coronavirus and its course.	Questionnaire T1, test T1
2	Pupils learn about the structure of a virus.	
3	Pupils learn about the reproduction and adaptation of a virus.	
4	Pupils learn about the function of vaccination.	
5	Pupils apply their knowledge by creating an initial poster for a new pandemic in the style of the health office. To do this, they evaluate information in the media, including social media.	Work sheet
6	Pupils prepare a presentation based on scientific findings and their poster. Pupils prepare arguments specific to their roles in the final discussion (mock TV show).	Poster
7	Pupils discuss their measures and whether they would be accepted by everyone. They reflect on their chosen measures with regard to the economy and other social actors.	Questionnaire T2, test T2, Video

topic needed a teacher-led introduction to ensure that all students understood the body's defences against viruses and the concept of vaccination. In these lessons, the content was taught frontally – the teacher facing the class, and the students were each given tasks in a dossier to recapitulate the learning content and ensure their understanding of it. The students were familiar with this form of teaching. In doing so, we also responded to the wishes of the teachers involved. Consequently, the second step, namely, the production of an educational poster with the help of sources from the Internet and subsequent group presentation, was somewhat tightly scheduled. The third step also included the exchange of arguments in smaller groups, but also in the whole class. The aim of this was to make the students more aware of their own values and moral concepts. We agree in line with Lee et al. (2013) that changes in values and moral concepts resulting from the implementation of a one-off SSI programme may be subtle at best. However, we believe that when trying to integrate SSI pedagogy into the classroom for the first time, sometimes modest steps have to be accepted until the approach is better known.

Sample

The data sample for this study consisted of three secondary school classes (higher track) from the Eastern part of Switzerland. All teachers from two schools were selected by us based on personal acquaintance. The students were all in Grade 9, and the mean age was 14.5 years. There were 25 girls and 24 boys. Of these 49 students, 11 spoke a language other than German at home. Due to individual absences, there were three missing data records at T1 and two at T2. All teachers were informed about the study's procedure, and parental consent was obtained for the video recordings. Data were anonymised. The study was conducted in accordance with the internal guidelines of the ethics committee of the implementing university.

Instruments

Our questionnaire, which was administered before and after the lesson series consisted of items measuring knowledge, beliefs and interest, as well as moral attitudes. For character and moral attitudes we applied the Global Citizens Assessment questionnaire (CVGA) (Lee et al., 2013) but dropped the items on ecological worldview as this was not a strong focus of our SSI. Background variables included information on the students' nationality, gender, and as a proxy for socioeconomic status (SES) we used 'how often books are a topic at home' (Sikora et al., 2019), given that SES encompasses not just income but also parents' educational attainment (Paterson, 1991). As a final evaluation by the learners, we asked whether they 'enjoyed the series of lessons' and whether they 'learned a lot'. Then there was an open question: 'What else I would like to say about the series of lessons … '. In the following the main constructs are explained including the scales taken from the CVGA:

(1) *Students' knowledge about the coronavirus.* This was measured with 12 items adapted from Puig et al. (2021). Sample items were 'What you know about the coronavirus … .' : 'Antibiotics can be used both to prevent and treat coronavirus' (not correct), or 'Vaccination against the coronavirus is a protective vaccination' (correct).

(2) *Science self-efficacy beliefs.* Four items were constructed to measure students' confidence for showing skills needed for our lesson series. The construct of self-efficacy refers to self-efficacy theory according to Bandura (1977). Sample items were 'I am good at explaining how to protect yourself from illness', 'I can easily understand how diseases develop in a newspaper report'. We obtained a Cronbach's alpha coefficient of .65 at Time 1 (T1)/Time 2 (T2), which is slightly below the cut-off criterion of $\alpha = .70$ due to a rather heterogeneous construction of our characteristic (Taber, 2018).

(3) *Interest in science (as a subject).* Four items aligned to Ainley and Ainley (2011). Sample items were 'I like the subject science and engineering', 'Science and engineering is boring'. We obtained a Cronbach's alpha coefficient of $\alpha = 0.94$ T1, $\alpha = 0.87$ T2.

(4) *Social and moral compassion.* This construct consists of three scales adapted from Lee et al. (2013). As in their study 'moral sensitivity' had low Cronbach's alpha values, we did not include it in our questionnaire. From the other two, 'empathic concerns' showed insufficient Cronbach's alpha values, and the scale was dropped. Nevertheless, we analysed the items individually. A sample item is: 'I feel like if I don't get vaccinated, then other people might suffer because of me'. Only one scale, 'perspective-taking,' with three items, showed sufficient values for internal consistency: $\alpha = 0.62$ T1, $\alpha = 0.80$ T2. A sample item is 'I try to take different opinions and perspectives into account when deciding whether or not to get vaccinated'.

(5) *Socioscientific accountability.* This construct consists of two scales adapted from Lee et al. (2013): 'feeling of responsibility' and 'willingness to act'. Both scales showed satisfying Cronbach's alpha values between $\alpha = 0.74$ and $\alpha = 0.82$ for the two time-points. Sample items were 'As I feel responsible for the spread of the coronavirus, I am willing to be vaccinated' for responsibility and 'I believe that the entire population needs to be involved in the measures against the coronavirus in order to stop the pandemic' for willingness to act.

(6) *Media literacy.* We planned to create a rubric to measure students' digital literacy based on completed worksheets with annotated Internet resources. Appropriate instruments would have been adapted from Breakstone et al. (2021). Unfortunately, it turned out that most of the students had only noted the source from the Federal Office of Public Health mentioned above. We had probably also provided too little time overall for the task, as they had to create a poster with health measures for the population at the same time. Due to the lack of variance, we decided not to develop the rubric. Although we did not ultimately include media literacy scores in our study, we mention the construct here because it is important to SSI.

(7) *Argumentation skills (qualitative rating).* The video recording of the final discussion was transcribed and coded using the software MAXQDA (Kuckartz & Rädiker, 2019). A rubric with five dimensions and four levels was constructed for the rating of the students' arguments (Table 2). The rubric was grounded in research by Mutakinati et al. (2018) and Kieke et al. (2019). Each coding unit consisted of a meaningful statement of one or more sentences. Two coders rated each unit, and differences were discussed until sufficient inter-rater reliability (ICC) of 0.81 (Koo & Li, 2016) was achieved.

Table 2. Rubric for rating the students' argumentation skills in the final discussion.

	Dimension	3 proficient	2 advanced	1 intermediate	0 beginning
A	Problem description with reference to virus infection	Clearly described (situation)	Partially described	Described to some extent	Missing
B	Argumentation	Thesis with justification (evidence, consequences)	Thesis with partial justification	Thesis without justification	Incomplete thesis without justification
C	Subject-specific quality (reference to viruses, infection, etc.)	Correct scientific justification, argumentation	Partially correct scientific justification, argumentation	Rudimentarily correct scientific justification, argumentation	Incorrect scientific justification, argumentation
D	Linguistic quality	Linguistically good and completely formulated contribution	Linguistically good but fragmentarily formulated contribution	Linguistically difficult to understand contribution	Linguistically incomprehensible or very difficult to understand contribution
E	Reference (if possible, to previous speaker)	Complete reference to other statements	Partial reference to other statements	Rudimentary reference to another statement	No reference to another statement

Data analysis

Due to the small sample size, we conducted only basic analyses (i.e. *t*-tests, repeated measures analysis of variance [ANOVA], and regression analyses). The *t*-test is appropriate for small sample sizes and quite robust in analyses of samples from non-normal distributions and samples with unequal variances. However, the low power of the small sample size made it more difficult to detect effects. Nevertheless, based on a power calculation (G*Power) for multivariate analysis of variance with repeated measures and an expected effect size of $f = .30$ and a power of .80, a sample of $N = 44$ was sufficient.

Data on the attitudes of the students before and after the lessons were tested for normality, linearity, multicollinearity, and homoscedasticity. Levene's test was used to verify the assumption of equal variances for the *t*-tests. Developments over time were analysed using a one-way ANOVA with repeated measures, which is known to be robust to violations of the normal distribution assumption.

The qualitative rating data were transformed into quantitative data and included in the overall data set. It needs to be mentioned that while a group of students prepared each role for the final discussion, only one of each group participated. In this respect, data on their argumentation skills are available for only 14 students. The power for a regression analysis with one predictor and an R^2 of .40 would nevertheless reach .80.

Results

We start with our first research question, how knowledge, moral attitudes, and interest towards COVID-19 as an SSI developed during the lesson series.

The pupils performed well on average in the knowledge test on the coronavirus (75% correct answers). However, performance decreased slightly over time instead of increasing (Table 3). The mean self-assed character and moral attitudes were positive at both points in time, although individual students' scores were also negative. The same also applies to self-efficacy, the belief that one is able to explain illnesses scientifically, or to the general interest in science. Over the seven lessons, there were significant positive changes in the scales for science interest and self-efficacy, but not for perspective-taking, feeling of responsibility and willingness to act. The latter three correlate with each other ($p < .01$). For the sake of completeness, we also mention that the three items of the 'Empathic concerns' scale, each analysed individually over time, showed no significant changes. As mentioned above, this scale showed insufficient Cronbach's alpha values. With regard to whether the students liked the series of lessons ($M = 4.87$; SD = 1.14) and whether they had learned something ($M = 4.69$; SD = 1.29), the students' responses showed high levels of agreement. The correlation between self-assessed learning gains and the knowledge test T2 was a low $r = .29$. We will come back to this in the discussion.

As already mentioned, we could not assess the students' media literacy due to missing variance in the students' documents. However, for those 14 students participating in the final discussions, we could measure their argumentation skills. Overall, they reached in our rating of $M = 2$ ($SD = .47$) which is advanced on our rubric ranging from 0 to 3 (Table 2).

We applied a *t*-test to check for gender differences. Only one difference was significant: at Time 2, girls ($M = 5.11$) showed significantly higher means in perspective-taking than boys ($M = 4.36$).

To tackle the second question, we performed a series of regression analyses. Our aim was to explain what factors of SSI understanding explained students' knowledge. In the final model, three items were used to explain 37% of the students' variance in their test performance after the lesson series. These items showed substantial beta values (Cohen, 1988), but only 'feeling of responsibility T2' was significant, while 'books topic at home' and 'test performance T1' missed significance (Table 4).

Self-assessed learning success correlated with Test T2 ($r = .31$; $p < .05$), and it might be of interest to show whether the same predictors help to explain students' variance. This was not the case. Two variables, 'enjoyed the lessons' and 'willingness to act' both showed low to medium beta effects, which were significant (Table 5). A considerable 58% of students' variance in self-assessed learning success could be explained. Thus students who enjoyed the lessons and showed 'willingness to act' (Lee et al., 2013) rated their learning success higher than others, while in the case of the 'real' test performance it was rather 'feeling of responsibility' (Table 4).

Table 3. Pre – and post-test means, standard deviations, and one-way ANOVA with repeated measurements.

	T1		T2			
	M	*SD*	*M*	*SD*	*p*	η^2
Test coronovirus	8.98	1.23	8.57	2.28	.21	.04
Perspective-taking	4.55	1.03	4.70	1.13	.16	.05
Feeling of responsibility	3.71	1.27	3.94	1.26	.09	.07
Willingness to act	4.13	1.01	4.25	1.32	.44	.02
Self-efficacy with regard to explaining science	3.95	.73	4.41	.69	<.01	.35
Interest in science	4.06	1.23	4.35	1.05	.01	.15

Note: $N = 44$; Test: 12 points max.; Scales: 6-point Likert scale (6 = strongly agree, 5 = agree, 4 = somewhat agree, 3 = somewhat disagree, 2 = disagree, and 1 = strongly disagree).

Table 4. Regression analysis summary for predicting students' knowledge on the COVID virus test T2.

Variable	*B*	*SE B*	*β*	*t*	*p*
Books topic at home (SES)	.528	.270	.259	1.955	.058
Test T1	.453	.242	.252	1.876	.068
Feeling of responsibility T2	.606	.255	.334	2.371	.023

Note: $R^2 = .37$; $N = 44$.

In two variables – self-efficacy beliefs and interest in science – the students showed significant changes over time. Hence, it is important to explain these positive developments. We start with students' science self-efficacy beliefs. We found three variables that helped to clarify differences between the students' self-efficacy beliefs at the end of the lesson series ($R^2 = .47$). The strongest predictor was self-efficacy beliefs before the lesson series ($\beta = .38$), indicating that students do not change their beliefs so easily (Table 6). Apart from the students' interest in science, it was again 'feeling of responsibility' that was important in our regression model, as we had found for test performance. This is in line with the social cognitive theory of Bandura (1977), in which it is hypothesised that changes in self-efficacy may have a significant impact on students' changes in behaviour (i.e. performance). Hence, the same predictors might be relevant for performance and self-efficacy beliefs.

The largest amount of explained variance in our series of regression analyses was achieved with the model for explaining students' interest in science after the lesson series ($R^2 = .71$; Table 7). However, this is mainly predicted by interest at T1, illustrating that interest in science is a rather stable construct; students' interest does not change quickly. Because interest at T1 is such a strong predictor ($\beta = .76$), there is not much variance left for other variables to explain. The predictor that comes close to significance is science self-efficacy beliefs T2, but the beta effect is small ($\beta = .16$). To sum up, interest rose over time, and those who showed high interest at T1 also showed high interest at T2.

Finally, there remains the question how variation in students' argumentation skills can be explained. To do this, we had to rely on a smaller sample of those students, who participated in the final discussion. Only one variable was significant: 'Books topic at home' as a proxy for SES (Table 8). This is not entirely surprising, given the strong evidence that children's language development (i.e. expressive vocabulary) is associated with the number of books available to them at home (Heppt et al., 2022). Hence, those students who possess language literacy have advantages when it comes to the discussion of SSI. This is an indication that not only scientific knowledge but also language is of fundamental importance when it comes to interpreting and constructing knowledge in science (Cavagnetto, 2010).

Discussion

The aim of our study was to explore the development of the students' knowledge, moral attitudes, and interest towards COVID-19 as an SSI over the course of a series of seven

Table 5. Regression analysis summary for predicting students' self-assessed learning success T2.

Variable	*B*	*SE B*	*β*	*t*	*p*
Enjoyed lessons T2	.66	.14	.59	4.92	<.001
Willingness to act T2	.26	.12	.26	2.20	.033

Note: $R^2 = .58$; $N = 44$.

Table 6. Regression analysis summary for predicting students' science self-efficacy beliefs T2.

Variable	*B*	*SE B*	*β*	*t*	*p*
Self-efficacy beliefs T1	.36	.13	.38	2.86	.007
Interest in science T2	.20	.09	.30	2.28	.028
Feeling of responsibility T2	.15	.07	.27	2.29	.028

Note: $R^2 = .47$; $N = 44$.

lessons to determine how these variables interact with each other. We were surprised that the knowledge test performance decreased over time. However, the difference was not significant, and we will comment below in the limits section on what problems may have existed. While Lee et al. (2013) and Powell et al. (2021) both reported positive significant developments in perspective-taking and feelings of responsibility but less clear change in willingness to act, in our study the students' showed no significant change in moral attitudes and values. Perhaps cloning, chosen by Powell et al. (2021) and Lee et al. (2013), appeared more morally salient to those students than did the question of COVID vaccination in our study. Furthermore, Lee's study took place in Korea, and one could refer here to Asian culture, in which service to the community plays a greater role (Hwang, 2015). Like Lindahl et al. (2011), who reported that SSI lessons increased interest in science in 25% of pupils, we demonstrated a positive development in our study. However, it turned out for us that most of this increase occurred among students who already showed higher interest levels at baseline. In addition, our own study found that self-efficacy beliefs increased, whereas the outcome of measurements by Lindahl et al. (2011) is unfortunately not clear. No gender-specific differences were reported in the two above-mentioned studies by Lee and Powell. In our study, however, we were able to show that girls scored higher than boys in perspective-taking. In this respect, it could be interesting in the future to examine gender differences more specifically in research on SSI.

In terms of argumentation skills, which we observed in the discussion rounds with role playing, we were actually quite satisfied. Overall, the students are already at quite a high level, and they also adopted perspectives appropriate to their role well. As a general impression, it needs to be stated that economic argumentations were at least as frequent as scientific ones. Another study that mentions scientific concepts tend to be used less as arguments (van der Leij et al., 2021) complements this finding. This raises some questions about the development of values among pupils. It would be interesting to clarify whether economic values are valued equally as highly as human values. Aziz and Johari (2023, p. 785) do not see this negatively, and they assess the perspective-taking of a businessman as 'empathetic and morally sensitive'. In a certain analogy, this can be compared with the statement of Powell et al. (2021) that the students in their study focussed on the benefits for humans and less on the question of what possibilities there are for finding a solution that takes equal account of human and animal welfare.

Table 7. Regression analysis summary for predicting students' interest in science T2.

Variable	*B*	*SE B*	*β*	*t*	*p*
Interest in science T1	.65	.08	.76	8.20	<.001
Science self-efficacy beliefs T2	.25	.14	.16	1.76	.086

Note: $R^2 = .71$; $N = 44$.

Table 8. Regression analysis for predicting students' argumentation skills T2.

Variable	*B*	*SE B*	*β*	*t*	*p*
Books topic at home (SES)	.30	.11	.63	2.72	.017

Note: $R^2 = .39$; $N = 14$.

In general, however, it seems to us that the transfer of scientific knowledge in argumentation rounds does not go quite as smoothly as expected. Fuchs and Jellema (2023) suggest the use of scaffolds to facilitate students' learning, e.g. providing them with exemplars and reminders of how to take notes from media. In our example lesson, it would be useful to provide examples of how scientific knowledge can be used in role playing.

Our second research question targeted the interplay of knowledge, media literacy, moral attitudes, and interest within the SSI lesson series. Specifically, we wanted to know what factors of SSI understanding explained students' knowledge, students' efficacy beliefs and interest, as well as their argumentation skills at the end of the lesson series. There is still a need for research here in particular. Overall, it was shown that socioscientific accountability is a strong factor that explains student differences in knowledge, interest and self-efficacy beliefs (Figure 2). When it comes to gains in knowledge, students with higher feeling of responsibility showed higher development in test performance, while willingness to act explains variance in students' self-perceived learning success. This suggests that an increase in socioscientific accountability may lead to an increase in science knowledge. It turns out that a feeling of responsibility also explains differences in students' self-efficacy beliefs, which in turn explains the variance in students' interest in science. Perspective-taking, which was part of the construct 'social and moral compassion,' could not help to explain interactions between the variables in our research model, but girls showed higher values.

Finally, for a small sample only, we discovered that high argumentation skills could be explained by students whose parents talk about books at home which stands for higher SES. It does seem to be the case that SES plays a role when it comes to argumentation in SSI lessons (Belland et al., 2015). The importance of language for the acquisition of

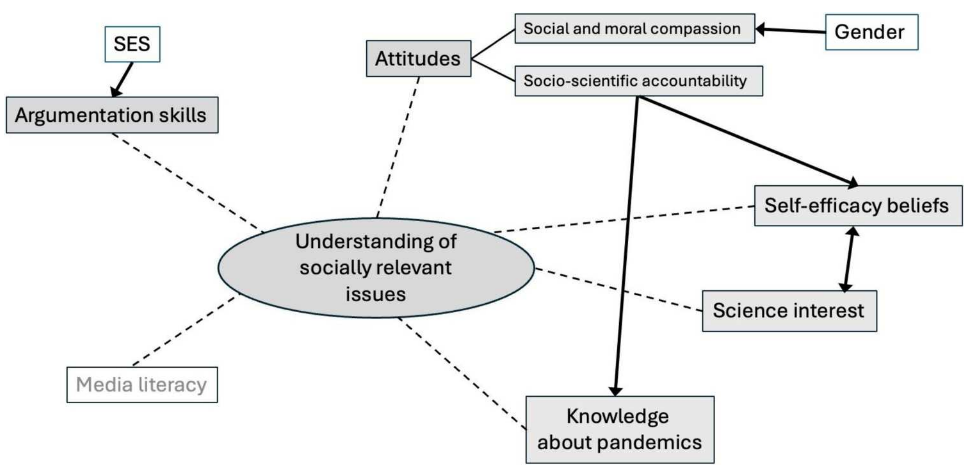

Figure 2. Research model with summary of demonstrated relationships.

scientific knowledge is discussed in detail by Cavagnetto (2010). He sees the SSI approach as a good way to immersively develop the language needed for science. In this way, the teacher can help to ensure that children with low SES can also acquire scientific literacy.

As our mixed-method study is exploratory with regard to instruments, certain limits were to be expected. Students' self-assessment of their success in learning was not matched by objective improvements in content knowledge as measured by test performance. This suggests that the decrease in test performance may be due to the fact that our test did not specifically reflect learning gains, as the items did not match the presented content well. The dilemma here was having to decide between a test instrument that had already been successfully used and one that had not yet been tested but had higher content validity. We believe that if the project is repeated, the test must better represent the learning content.

Furthermore, since not all of the character and value scales defined by Lee et al. (2013) and applied in this study showed satisfactory reliability values, we take up a suggestion by Atabey and Topçu (2024) that more and different scales for assessing students' character and value development should be constructed. They believe that there might be other aspects that could be explored through SSI-based teaching for character and values development that would also be interesting for research. To measure students' development more thoroughly, one could also refer to the work of van der Leij et al. (2021). They measured students' morality in socioscientific issues with regard to perspective-taking, moral consequences, and taking action but in much more detailed subdimensions. Comparably to self-efficacy beliefs in our research, 'ego-control' was included as part of morality, When we talk about values or attitudes in relation to SSI, we should think not only of the cognitive components but also of the affective ones. In their own study, Gao et al. (2021) added an emotional component to their series of SSI lessons. The aim was for students to develop emotional competence, e.g. to listen empathically to others, something also suggested by Fowler et al. (2009).

While in other studies (Lee et al., 2013; Powell et al., 2021) socioscientific accountability has been somewhat difficult to interpret, here this variable is clearly important in science learning, as shown not only by development over time but also by the relationship between the variables. We suggest that such interactions should also be analysed with larger samples and in structural equation models. It would also be important to calculate such models for different SSI topics in parallel. More knowledge is needed on the extent to which the selected topic affects the relationships. Qualitative methods that can be combined with such more complex quantitative methods are also desirable, for example, in assessing media literacy or argumentation performance.

With regard to teaching practices, our project was primarily about trying out the lesson design. The implementation was the responsibility of the researchers, while the teachers were able to observe how we implement SSI as a model. From the teachers' point of view, there is a legitimate question as to how the content of the science curriculum to be covered can be managed with the rather time-consuming approach in SSI lessons, involving media research, discussions and reflections. Further thought needs to be given to time-optimised learning settings that are rich in learning content. It remains to be seen what impact our project will have on the lessons of the teachers involved. Whether they include SSI in their repertoire would have to be analysed in a next step. We certainly hope that the interventions and results presented in this study could serve as a model for teachers in the K–12 system and thus further spread the SSI idea in our country and elsewhere.

Authors' contribution

RS and FR carried out the investigation, coded the data, and analysed and discussed the results. All authors designed the research project, developed the instruments, interpreted the results, and commented on the manuscript.

Disclosure statement

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Data availability

The data will be made available upon request.

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