DOI: 10.2436/20.2003.02.242 http://scq.iec.cat/scq/index.html

ISSN 2013-1755, SCQ-IEC Educació Química EduQ número 31 (2023), p. 40-49

From science to society: problem-solving towards socioscientific decision-making in chemistry

De la ciència a la societat: resolució de problemes per a la presa de decisions sociocientífiques en química

Miia Rannikmäe, Jack Holbrook, Regina Soobard , T. B. M. Chowdhury / University of Tartu, Estonia

abstract

The teaching of chemistry not only impacts on the future workforce but also enables students to be involved in gaining a range of educational competences. However, the value of learning chemistry is not immediately apparent and can often ignore the need for relevance, especially societal relevance. This article looks at the purpose of teaching chemistry and focuses on an approach that builds on relevance towards the development of problem-solving and introducing socioscientific decision-making.

keywords

Chemistry, scientific literacy, socioscientific issues, problem-solving, decision-making.

resum

Els estudis de química no només han de servir per tenir més professionals d'aquest àmbit en el futur, sinó que han de servir perquè els estudiants adquireixin competències científiques per a la vida. Tanmateix, el valor de l'aprenentatge de la química no és evident de manera immediata i sovint pot semblar poc necessari i rellevant, especialment per a la societat. Aquest article analitza la finalitat de l'ensenyament de química i se centra en un enfocament que es basa en la seva importància per a la resolució de problemes i la presa de decisions sociocientífiques.

paraules clau

Química, alfabetització científica, qüestions sociocientífiques, resolució de problemes, presa de decisions.

Introduction

Teaching within the chemistry classroom always has a dilemma between two paradigms:

1. Do we teach the subject of chemistry so that this provides one of the learning components and which, when combined with the provision of other subjects, forms the overall education provision for students?

or

2. Do we seek to provide an education for students, one aim of this being the education being promoted through the teaching in the chemistry classroom?

Holbrook and Rannikmäe (2009) stated that just teaching the subject of chemistry in isolation is seen as promoting the subject as purely an academic exercise, potentially isolating this from the overall education provision to be gained at school. This approach can be viewed as establishing key chemistry-related ideas through a logical teaching progression (e.g. following a concept map) and stressing important subject-related uses of the chemistry learned. Such studying of analytical subject learning is not so much for the benefit of society as a whole, although it can prepare students to reflect on the uses, or misuses of applications within the society. However, this approach can be expected to involve students in the development of problem-solving skills through the learning of chemical processes and the ability to apply chemistry-related solutions for industrial processes and applications for the advancement of society's use, as well as an awareness of learning chemistry for future careers.

On the other hand, learning chemistry can be viewed as an educational challenge. As such, it seeks to establish the social relevance for the acquisition of conceptual chemistry ideas, the importance of developing an understanding of conceptual approaches which build on basic ideas enabling complex analytical developments, whilst also debating:

(i) The balance of embedding conceptual elements of the teaching of chemistry for the benefit of society as a whole,
(ii) The concerns that society faces and enabling decisions making actions that can be considered, as well as
(iii) Preparing students for future careers.

A possible approach for the latter can start from previously identified concerns or issues within society, developing educational abilities through scientific conceptual understanding (on a need-to-know basis) in order to acquire problem-solving chemistry skills, and then applying this learning to socioscientific decision-making in addressing the importance of scientific advances in the light of the greater society need.

A move towards the latter 'education through chemistry' approach has gained ground (Holbrook, 2010), noting concerns that the current provision for the learning of chemistry:

– Is unpopular and irrelevant in the eyes of students (Gilbert, 2006; Salta and Koulougliotis, 2020; Wu et al., 2001)
– Does not promote higher order cognitive skills (da Silva and de Vasconcelos, 2022; Zoller and Tsaparlis, 1997)
– Leads to gaps between students' wishes and teachers' teaching (Byusa et al., 2022; Erman, 2017)
– Is not changing, because teachers are afraid of change and need guidance (Cossa and Uamusse, 2015; Roehrig and Kruse, 2005)
– Does not aspire students to take up a career in science-related fields (OECD, 2008; Shwartz et al., 2021)

These above can be equated with visions for attaining scientific literacy put forward by Roberts (2007; 2014), where the first, or traditional, includes an understanding of scientific processes, practices and basic principles within a strictly scientific context and clearly relates to an emphasis on the formation of science knowledge and skills.

Vision II, seen as more progressive, adds values and skills necessary for becoming a citizen, and is seen as reflecting on real-life situations that are scientific in nature but influenced by other factors, such as social, political and ethical issues. This latter perspective focuses on decision-making via negotiation related to scientific issues for all citizens, not just those who intend to take up a scientific career.

In chemistry teaching, it is important not to be limited to the first ideology, despite the fact that scientific knowledge and skills play a significant role in the learning. Isolation of scientific knowledge and skills from value judgments and the skills needed within society creates a contradiction between developing

Even today, in systems where education is intended for all, content knowledge and conceptual understanding still seem to prevail. In chemistry textbook chapter headings are dominated by the subject matter and with heavy inclusion of scientific terminology.

attributes for a changing society and recognising the nature of science and its place in driving innovation. Yet, it has been traditional to educate students in school, especially secondary schools, through subject domains and within lessons named according to the domain. This gives the impression that education is the gaining of subject matter. Thus, today in most countries, science lessons are offered in the curriculum, specified as science, or as one or more of its sub-components (e.g. biology, chemistry, physics), or perhaps as a combination of these (e.g. physical science). It does not have to be this way, of course, as it can be amplified by the concept of an integrated day, implemented at the primary level in a number of countries (Deehan, 2022; Lee et al., 2015).

So, what is intended in science lessons? A traditional view is that teaching, driven by the subject learning outcomes, is about the acquiring of information and concepts in order to promote intellectual development and provide a base for further subject learning at a higher level. This especially comes about when education is selective and not all students are able to successfully compete for the opportunity to progress to the higher levels of learning (Valladares, 2021). But even today, in systems where education is intended for all (and usually compulsory up to 15/16 years of age), content knowledge and conceptual understanding still seem to prevail. One look at the standard science or chemistry textbook shows chapter headings dominated by the subject matter and with heavy inclusion of scientific terminology.

Nevertheless, we are very aware of the dilemmas associated with a subject dominant approach:

1. The science, or chemistry content keeps increasing and even more, increasing at a greater and greater pace (sometimes described as exponential).
2. School science subject teaching has both an obligation to the subject and its developments, but also to the need for education within a modern society, where increasingly technology provides the visible face of science, and
3. Issues associated with technology within society bring science into both an interdisciplinary, social focus and are called upon to play a role in the decision-making processes within society.

To tackle the first dilemma, curricula are forced to pick and choose: for example, is the periodic table really a basis for studying chemistry, when organic chemicals dominate the modern technological advances in the material world? Do chemistry curricula need to promote mathematical approaches to phenomena when, in today's world, the application of computer programs has overtaken such needs? And can an emphasis on conceptual chemistry meet the demands in society for tackling sustainability demands?

With dilemmas 2 and 3, it is appropriate to reflect on whether the goal is the teaching of science through the educational provision, or do we accept the second paradigm and see this as 'education through science'? Table 1 below seeks to compare both.

Chemistry through education	Education through chemistry
Learn the fundamental chemistry knowledge, concepts, theories and laws.	Learn the chemistry knowledge and concepts important for understanding and handling socioscientific issues within society.
Undertake the processes of chemistry through inquiry learning as part of the development of learning to be a scientist (chemist).	Undertake investigatory chemistry problem-solving to better understand the chemistry background related to socioscientific issues within society.
Gain an appreciation of the nature of science from a chemical science point of view.	Gain an appreciation of the nature of science from a societal point of view.

Table 1. A comparison of similarities and differences in philosophical emphases between 'chemistry through education' and the alternative 'education through chemistry'.

Promoting students' decision-making skills using socioscientific issues

In promoting students' decision-making skills, many researchers have advocated the inclusion of socioscientific issues (SSIs) in the teaching-learning of science (Cebesoy, 2021; Sadler and Zeidler, 2005; Sakschewski et al., 2014). Zeidler et al. (2005; 2019) define SSIs as scientifically embedded societal concerns, which are controversial in nature, and relevant to the students. Although in the English language, the terms *problem* and *issue* are often used interchangeably, socioscientific issues stand apart from the scientific problems. For example, a scientific problem can be solved through the application of scientific methods, such as experimentation, observation, and analysis. However, the resolution of an SSI requires multiple epistemic perspectives, not only scientific but also social, moral, ethical, political or even economic (Chowdhury et al., 2020). Examples of SSIs include cloning, climate change, vaccination, clean water, animal testing, or even artificial food colours (Hancock et al., 2019; Morris, 2014; Mueller and Zeidler, 2010; Saunders and Rennie, 2013).

In chemistry, some examples of SSI are: selecting the location of nuclear power plants, ot the use of harmful ingredients in shower gels and musk fragrances (Marks and Eilks, 2010; Ozturk and Yilmaz-Tuzun, 2017). Understandably, these issues require consideration beyond chemistry facts. Hence, in addressing SSIs, students may be required to undertake dialogues, discussion, debate and even argumentation through utilizing multiple points of view, and thus promote students':

– reasoning skills (Lee and Witz, 2009);

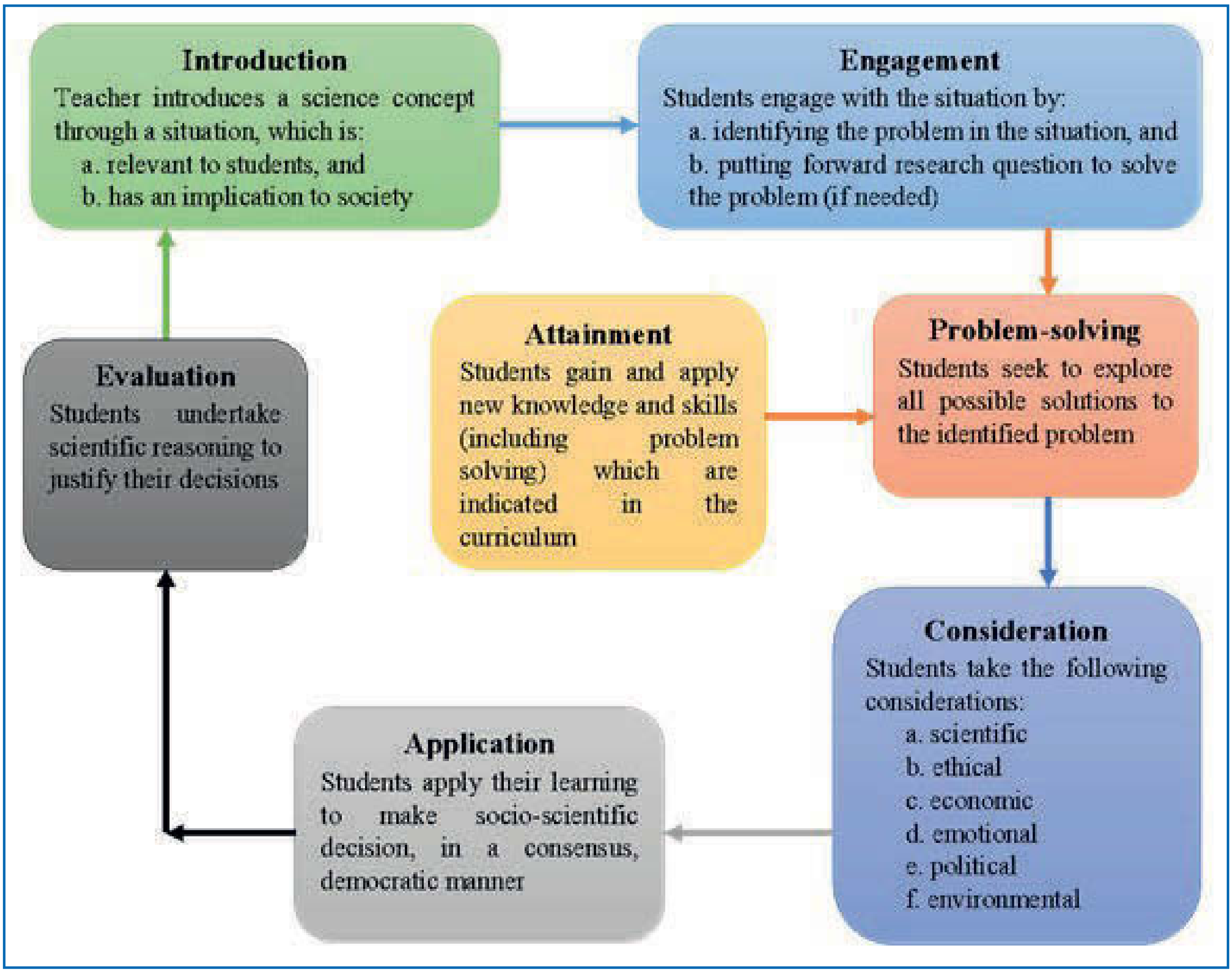


Figure 1: Phases of teaching to promote socioscientific decision-making.

– values and emotions (Reis and Galvão, 2004);
– critical thinking (Sadler et al., 2006), and
– a positive attitude towards scientific information (Tidemand and Nielsen, 2017).

In resolving SSIs, students need to acquire an undertaking of decision-making in a consensus, democratic manner (Eş and Öztürk, 2021; Yacoubian and Khishfe, 2018). Consensus and democratic decision-making skills are often linked to citizenship attributes and hence, it is not surprising that SSIs are further expected to promote students as future citizens who are personally responsible, participatory, justice oriented and politically concerned (Chowdhury et al., 2020).

In implementing SSI in the classroom, researchers suggest that teaching needs to be contextualized (Owens et al., 2021), even situated (Sadler, 2011), and most importantly, student-centred (Eastwood et al., 2012). By providing SSI as a context in which students learn chemistry, students can be expected to gain an awareness of the interrelationship between social, political and scientific perspectives, as they incorporate important chemistry content and practices into the argumentation, reasoning and decision-making processes (Driver et al., 2000; Hodson, 2003; Sadler, 2011; Zohar and Nemet, 2002). In the book *Socioscientific Issues in the Classroom: Teaching, Learning, and Research* (Sadler, 2011), science education researchers from around the world present examples of classroom-based SSI research with special attention to the nature of SSI interventions and implications for teaching and learning of SSI.

> Moving from problem-solving towards socioscientific decision-making can be expected to bring socioscientific issues into the chemistry classroom, seeking to make chemistry teaching more meaningful and relevant to students.

For personal and social development, such skills are viewed as cross-disciplinary and not necessarily dependent directly on concrete subject knowledge, being strongly interrelated to values and attitudes towards chemistry. Thus, moving from problem-solving towards socioscientific decision-making can be expected to bring socioscientific issues into the chemistry classroom, seeking to make chemistry teaching more meaningful and relevant to students.

The following figure 1 illustrates a philosophical approach behind the cognitive/contextual focus, which is based on the recognition that there is a need to initiate science education learning from a *familiar and student relevant socioscientific issue, thus establishing intrinsic relevance*. The figure illustrates how relevance is intended to trigger students' self-motivation to promote self-involvement in the learning. Such motivation is sustained by student involvement, but also by extrinsically relevant aspects supplied by the teacher.

Introducing chemistry through a student relevant situation

As figure 1 demonstrates: the use of a relevant context-based situation is important, as relevance is a very useful precursor for developing students' personal interest and a powerful stimulus for science learning (Gilbert, 2006; Pilot and Bulte, 2006). The theoretical construct is that relevance drives students' motivation to learning and once relevance is established, the motivation for involvement can go beyond the context-based scenario and lead into scenario-related conceptual science learning. Unfortunately, standard approaches, which assume science is inherently interesting for students, if taught well, have been shown to have little appeal to many students at the secondary level, for a lack of personal and social relevance (Osborne et al., 2003). In addressing this concern, researchers suggest introducing a chemistry topic through socioscientific issues, considering that socioscientific issues are usually embedded within the context of students' personal and social relevance (Hancock et al., 2019).

Figure 2: Dead Sea – a wonder in the world.

The theoretical construct is that relevance drives students' motivation to learning and once relevance is established, the motivation for involvement can go beyond the context-based scenario and lead into scenario-related conceptual science learning.

An example of a situation to introduce chemistry in the classroom is the dead sea. A socioscientific issue associated with the dead sea is whether Israel should develop tourism or protect the natural heritage around the dead sea. The SSI in this case is relevant to both chemistry and society. In addition to that, it also potentially initiates students' interest and motivation to learn chemistry.

Enabling students' engagement with the situation

A relevant SSI provides students with a desire to engage in the chemistry learning, through identifying the problem in the situation, and seeking to solve it by utilising an important chemistry learning component. The learning approach is the students' emotional engagement first, leading to chemistry learning second. This contrasts with the usual suggested approach: make the chemistry itself interesting within the context so that it then motivates students and at the same time is also relevant to society (Stuckey et al., 2013).

Incorporating student-led problem-solving

The solution to the chemistry problem, carefully detailed and explored, is expected to be the gateway to the decision-making stage, where the knowledge gained from the problem-solving stage can be used to reflect on the given scenario. A good approach for consolidating this problem-solving in chemistry is to construct a concept map.

Creating a concept map can be an introduction to conceptual chemistry learning. It can include new chemistry ideas. To be useful, the learning needs to be put into a scientific context and, in particular, interrelate with other chemistry knowledge. Novak et al. (1983) and Stevenson et al. (2017) have shown that scientific concepts can be interlinked by means of a concept map, based on a theoretical construct to solve a problem. Additionally, compiling concept maps can be a useful assessment exercise in which students can illustrate their learning or scientific patterns —a valuable component in developing chemistry ideas further.

Developing curriculum stipulated chemistry knowledge and skills

A concept map leads students to identify the relevant chemistry knowledge and skills they need to solve the problem. In gaining such knowledge and skills through a constructivist approach, teachers need to take the role of facilitators, with students taking an active role in problem-solving (Bruner, 1966). Thus, teachers need to guide students to construct their learning in a self-directed approach and realise that the more practice students have, the more easily and the more capable they are likely to be undertaking chemistry problem-solving.

Considering factors beyond chemistry

An 'education through chemistry' approach suggests that only gaining chemistry conceptualisation is not sufficient, and advocates chemistry learning including the resolution of complex socioscientific issues. As SSIs are controversial and ill-structured, they often require consideration from multiple points of views to reach a resolution. Hence, students are required to consider not only the scientific, but also ethical, economic, emotional, political, environmental and value-laden aspects (Chowdhury, 2022). In addition to that, Zeidler et al. (2019) also suggest a need to consider tolerance, mutual respect, and moral sensitivity in addressing a socioscientific issue.

Applying chemistry learning in socioscientific decision-making

Socioscientific decision-making, utilising chemistry learning, has two major components. First, students are encouraged to consolidate the chemistry ideas introduced. This is achieved by involving students in additional tasks (above and beyond the module) related to the concepts, preferably interlinking with students' prior concepts, answering written exercises; utilising the jigsaw method, etc. And second, students are required to utilise the chemistry ideas gained in order to (i) be able to transfer scientific ideas to a new, contextual situation, and (ii) participate meaningfully in a decision-making exercise in order to arrive at a justified decision related to the initial socioscientific situation.

> An 'education through chemistry' approach suggests that only gaining chemistry conceptualisation is not sufficient, and advocates chemistry learning including the resolution of complex socio-scientific issues.

Evaluation of the chemistry-embedded socioscientific decision

This involves student groups, or whole class interactions, in activities such as debates, role playing or discussions. Students are expected to put forward their points of view, the teacher ensuring they incorporate the new chemistry in a meaningful and appropriate correct manner. Students are thus involved in aspects of argumentation, as well as communicating the new chemistry ideas in a conceptually correct manner. The end result is a set of small group decisions or a consensus decision made by the class as a whole. The actual decision is not, in itself, as important as the justifications put forward, but is expected to comply with social values accepted by the local society as a whole.

An example of the above-mentioned framework is briefly introduced in the following:

Conclusion

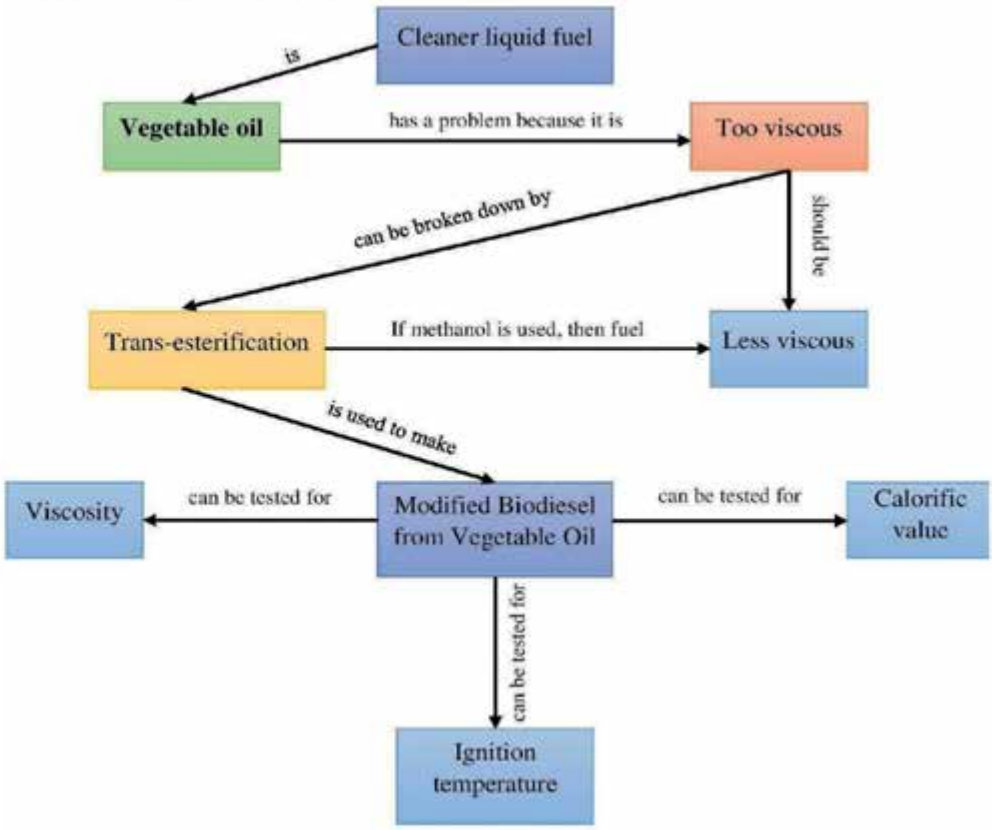
This article promotes paradigm 2 by arguing for and putting forward a focus on 'education through chemistry' as opposed to 'chemistry through education' and in so doing, builds on relevance towards the development

Introduction: Teacher provides students with a scenario involving a bronchitis patient, who needs to live in a world with less hydrocarbon and sulphur emissions. Since fuels based on vegetable oils produce much less hydrocarbon emissions and practically no sulphur emissions, the teacher introduces the use of vegetable oils by using this to make biodiesel. But one problem with this is, biodiesel is made from food that we eat, like corn. So, if we make biodiesel, there is the danger that it can take away food from hungry mouths.

Engagement: Students identify the dilemma in the scenario, whether or not to use vegetable oils as a fuel.

Problem-solving: Students draw a concept map to identify the possible inter-connections between the relevant concepts. An example of a possible concept map, related to the use of vegetable oil to solve the problem of make a fuel, is demonstrated in the figure 2.

Figure 3: Exemplary concept map



Attainment: Students gain and apply new knowledge and skills, relevant to the topic, such as esters (consolidation), esterification (consolidation), biodiesel, non-aqueous catalyst, calorific value of fuels.

Consideration: Students take the chemistry conceptual learning, the economic aspect of fuel industry, environmental impact of hydrocarbon and sulphur emissions, health and emotional aspect of using biodiesel that come from food and so on.

Application: Students apply their learning to make socio-scientific decision, on whether or not to use vegetable oil as a fuel in a consensus, democratic manner.

of learning through a problem-solving exercise before going further and introducing socioscientific decision-making, relating chemistry to the real world. This, it is proposed, makes the learning of chemistry more interesting.

References

Bruner, J. (1966). *Toward a theory of instruction* (vol. 59). Harvard University Press.

Byusa, E.; Kampire, E.; Mwesigye, A. R. (2022). «Game-based learning approach on students' motivation and understanding of chemistry concepts: A systematic review of literature». *Heliyon*, vol. 8, no. 5, e09541. https://doi.org/https://doi.org/10.1016/j.heliyon.2022.e09541

Cebesoy, U. B. (2021). «Pre-service Science Teachers' Informal Reasoning Patterns and Risk Perceptions in SSI: Case of Gene Therapy». *European Journal of Science and Mathematics Education*, vol. 9, no. 4, pp. 211-229. https://doi.org/10.30935/SCIMATH/11237

Chowdhury, T. B. M. (2022). *Establishing trans-contextual science education in promoting active informed citizenry for societal development*. Dissertationes pedagogicao 'scientiarum universitatis Tartuensis, vol. 12. University of Tartu. https://dspace.ut.ee/handle/10062/84010

Chowdhury, T. B. M.; Holbrook, J.; Rannikmäe, M. (2020). «Socioscientific Issues within Science Education and their Role in Promoting the Desired Citizenry». *Science Education International*, vol. 31, no. 2, pp. 203-208. https://doi.org/https://doi.org/10.33828/sei.v31.i2.10

Cossa, E. F. R.; Uamusse, A. A. (2015). «Effects of an In-service Program on Biology and Chemistry Teachers' Perception of the Role of Laboratory Work». *Procedia - Social and Behavioral Sciences*, vol. 167, pp. 152-160. https://doi.org/https://doi.org/10.1016/j.sbspro.2014.12.656

da Silva, R. A.; de Vasconcelos, F. C. G. C. (2022). «Learning through chemistry simulations: an analysis of cognitive skill levels». *Education and Information Technologies*, vol. 27, no. 5, pp. 6967-6987. https://doi.org/10.1007/s10639-022-10911-1

Deehan, J. (2022). «Primary Science Education in Australian Universities: An Overview of Context and Practice». *Research in Science Education*, vol. 52, no. 6, pp. 1735-1759. https://doi.org/10.1007/s11165-021-10026-6

Driver, R.; Newton, P.; & Osborne, J. (2000). «Establishing the Norms of Scientific Argumentation in Classrooms». *Science Education*, vol. 84, no. 3, pp. 287-312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.3.CO;2-1

Eastwood, J. L.; Sadler, T. D.; Zeidler, D. L.; Lewis, A.; Amiri, L.; Applebaum, S. (2012). «Contextualizing Nature of Science Instruction in Socioscientific Issues». *International Journal of Science Education*, vol. 34, no. 15, pp. 2289-2315. https://doi.org/10.1080/09500693.2012.667582

Erman, E. (2017). «Factors contributing to students' misconceptions in learning covalent bonds». *Journal of Research in Science Teaching*, vol. 54, no. 4, pp. 520-537.

E., H.; Öztürk, N. (2021). «An Activity for Transferring the Multidimensional Structure of SSI to Middle School Science Courses: I Discover Myself in the Decision-Making Process with SEE-STEP!». *Research in Science Education*, vol. 51, no. 3, pp. 889-910. https://doi.org/10.1007/s11165-019-09865-1

Gilbert, J. K. (2006). «On the Nature of "Context" in Chemical Education». *International Journal of Science Education*, vol. 28, no. 9, pp. 957-976. https://doi.org/10.1080/09500690600702470

Hancock, T. S.; Friedrichsen, P. J.; Kinslow, A. T.; Sadler, T. D. (2019). «Selecting Socioscientific Issues for Teaching». *Science & Education*, vol. 28, no. 6-7, pp. 639-667. https://doi.org/10.1007/s11191-019-00065-x

Hodson, D. (2003). «Time for action: Science education for an alternative future». *International Journal of Science Education*, vol. 25, no. 6, pp. 645-670. https://doi.org/10.1080/09500690305021

Holbrook, J. (2010). «Education through science as a motivational innovation for science education for all». *Science Education International*, vol. 21, no. 2, pp. 80-91. http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=EJ890663

Holbrook, J.; Rannikmäe, M. (2009). «The meaning of scientific literacy». *International Journal of Environmental and Science Education*, vol. 4, no. 3, pp. 275-288.

Lee, H.; Witz, K. G. (2009). «Science teachers' inspiration for teaching socioscientific issues: Disconnection with reform efforts». *International Journal of Science Education*, vol. 31, no. 7, pp. 931-960.

Lee, Y. J.; Kim, M.; Yoon, H. G. (2015). «The Intellectual Demands of the Intended Primary Science Curriculum in Korea and Singapore: An analysis based on revised Bloom's taxonomy». *International Journal of Science Education*, vol. 37, no. 13, pp. 2193-2213. https://doi.org/10.1080/09500693.2015.1072290

Marks, R.; Eilks, I. (2010). «Research-based development of a lesson plan on shower gels and musk fragrances following a socio-critical and problem-oriented approach to chemistry teaching». *Chemistry Education Research and Practice*, vol. 11, no. 2, pp. 129-141. https://doi.org/10.1039/c005357k

Morris, H. (2014). «Socioscientific Issues and Multidisciplinarity in School Science Textbooks». *International Journal of Science Education*, vol. 36, no. 7, pp. 1137-1158. https://doi.org/10.1080/09500693.2013.848493

Mueller, M. P.; Zeidler, D. L. (2010). «Moral--Ethical Character and Science Education: EcoJustice Ethics Through Socioscientific Issues (SSI)». In D. J. Tippins, M. P. Mueller, M. van Eijck, & J. D. Adams (Eds.), *Cultural Studies and Environmentalism: The Confluence of EcoJustice, Place-based (Science) Education, and Indigenous Knowledge Systems*,

pp. 105-128. Springer Netherlands. https://doi.org/10.1007/978-90-481-3929-3_8
Novak, J. D.; Gowin, D. B.; Johansen, G. T. (1983). «The use of concept mapping and knowledge vee mapping with junior high school science students». *Science Education*, vol. 67, no. 5, pp. 625-645. https://doi.org/10.1002/sce.3730670511
OECD. (2008). «Encouraging student interest in science and technology studies». In *Encouraging Student Interest in Science and Technology Studies*, vol. 9789264040. Organisation for Economic Cooperation and Development (OECD). https://doi.org/10.1787/9789264040892-en
Osborne, J.; Simon, S.; Collins, S. (2003). «Attitudes towards science: A review of the literature and its implications». *International Journal of Science Education*, vol. 25, no. 9, pp. 1049-1079.
Owens, D. C.; Sadler, T. D.; Friedrichsen, P. (2021). «Teaching Practices for Enactment of Socioscientific Issues Instruction: an Instrumental Case Study of an Experienced Biology Teacher». *Research in Science Education*, vol. 51, no. 2, pp. 375-398. https://doi.org/10.1007/s11165-018-9799-3
Ozturk, N.; Yilmaz-Tuzun, O. (2017). «Preservice Science Teachers' Epistemological Beliefs and Informal Reasoning Regarding Socioscientific Issues». *Research in Science Education*, vol. 47, no. 6, pp. 1275-1304. https://doi.org/10.1007/s11165-016-9548-4
Pilot, A.; Bulte, A. M. W. (2006). «The Use of "Contexts" as a Challenge for the Chemistry Curriculum: Its successes and the need for further development and understanding». *International Journal of Science Education*, vol. 28, no. 9, pp. 1087-1112. https://doi.org/10.1080/09500690600730737
Reis, P.; Galvão, C. (2004). «The impact of socioscientific controversies in Portuguese natural science teachers' conceptions and practices». *Research in Science Education*, vol. 34, no. 2, pp. 153-171.
Roberts, D. A. (2007). *Scientific Literacy/Science Literacy in Handbook of Research on Science Education (eds. Abell, S. & Lederman, NG)*, pp. 729-780. Mahwah, New Jersey: Lawrence Erlbaum.
Roberts, D. A.; Bybee, R. W.; Bybee, R. W. (2014). *Scientific Literacy, Science Literacy, and Science Education*, pp. 559-572. https://doi.org/10.4324/9780203097267-38
Roehrig, G. H.; Kruse, R. A. (2005). «The role of teachers' beliefs and knowledge in the adoption of a Reform-Based curriculum». *School Science and Mathematics*, vol. 105, no. 8, pp. 412-422.
Sadler, T. D. (2011). «Situating Socioscientific Issues in Classrooms as a Means of Achieving Goals of Science Education». In T. D. Sadler (Ed.), *Socioscientific Issues in the Classroom: Teaching, Learning and Research*, pp. 1-9. Springer Netherlands. https://doi.org/10.1007/978-94-007-1159-4_1
Sadler, T. D.; Amirshokoohi, A.; Kazempour, M.; Allspaw, K. M. (2006). «Socioscience and ethics in science classrooms: Teacher perspectives and strategies». *Journal of Research in Science Teaching*, vol. 43, no. 4, pp. 353-376. https://doi.org/10.1002/tea.20142
Sadler, T. D.; Zeidler, D. L. (2005). «Patterns of informal reasoning in the context of socioscientific decision making». *Journal of Research in Science Teaching*, vol. 42, no. 1, pp. 112-138. https://doi.org/10.1002/tea.20042
Sakschewski, M.; Eggert, S.; Schneider, S.; Bögeholz, S. (2014). «Students' Socioscientific Reasoning and Decision-making on Energy-related Issues—Development of a measurement instrument». *International Journal of Science Education*, vol. 36, no. 14, pp. 2291-2313. https://doi.org/10.1080/09500693.2014.920550
Salta, K.; Koulougliotis, D. (2020). «Domain specificity of motivation: chemistry and physics learning among undergraduate students of three academic majors». *International Journal of Science Education*, vol. 42, no. 2, pp. 253-270. https://doi.org/10.1080/09500693.2019.1708511
Saunders, K. J.; Rennie, L. J. (2013). «A Pedagogical Model for Ethical Inquiry into Socioscientific Issues In Science». *Research in Science Education*, vol. 43, no. 1, pp. 253-274. https://doi.org/10.1007/s11165-011-9248-z
Shwartz, G.; Shav-Artza, O.; Dori, Y. J. (2021). «Choosing Chemistry at Different Education and Career Stages: Chemists, Chemical Engineers, and Teachers». *Journal of Science Education and Technology*, vol. 30, no. 5, pp. 692-705. https://doi.org/10.1007/s10956-021-09912-5
Stevenson, M. P.; Hartmeyer, R.; Bentsen, P. (2017). «Systematically reviewing the potential of concept mapping technologies to promote self-regulated learning in primary and secondary science education». *Educational Research Review*, vol. 21, pp. 1-16. https://doi.org/https://doi.org/10.1016/j.edurev.2017.02.002
Stuckey, M.; Hofstein, A.; Mamlok-Naaman, R.; Eilks, I. (2013). «The meaning of "relevance" in science education and its implications for the science curriculum». *Studies in Science Education*, vol. 49, no. 1,

pp. 1-34. https://doi.org/10.1080/03057267.2013.802463

Tidemand, S.; Nielsen, J. A. (2017). «The role of socioscientific issues in biology teaching: from the perspective of teachers». *International Journal of Science Education*, vol. 39, no. 1, pp. 44-61. https://doi.org/10.1080/09500693.2016.1264644

Valladares, L. (2021). «Scientific Literacy and Social Transformation». *Science & Education*, vol. 30, no. 3, pp. 557-587. https://doi.org/10.1007/s11191-021-00205-2

Wu, H. K.; Krajcik, J. S.; Soloway, E. (2001). «Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom». *Journal of Research in Science Teaching*, vol. 38, no. 7, pp. 821-842. https://doi.org/10.1002/tea.1033

Yacoubian, H. A.; Khishfe, R. (2018). «Argumentation, critical thinking, nature of science and socioscientific issues: a dialogue between two researchers». *International Journal of Science Education*, vol. 40, no. 7, pp. 796-807. https://doi.org/10.1080/09500693.2018.1449986

Zeidler, D. L.; Herman, B. C.; Sadler, T. D. (2019). «New directions in socioscientific issues research». *Disciplinary and Interdisciplinary Science Education Research*, vol. 1, no. 1, p. 11. https://doi.org/10.1186/s43031-019-0008-7

Zeidler, D. L.; Sadler, T. D.; Simmons, M. L.; Howes, E. V. (2005). «Beyond STS: A research-based framework for socioscientific issues education». *Science Education*, vol. 89, no. 3, pp. 357-377. https://doi.org/10.1002/sce.20048

Zohar, A.; Nemet, F. (2002). «Fostering students' knowledge and argumentation skills through dilemmas in human genetics». *Journal of Research in Science Teaching*, vol. 39, no. 1, pp. 35-62. https://doi.org/10.1002/tea.10008

Zoller, U.; Tsaparlis, G. (1997). «Higher and lower-order cognitive skills: The case of chemistry». *Research in Science Education*, vol. 27, no. 1, pp. 117-130. https://doi.org/10.1007/BF02463036

Miia Rannikmäe

Is professor in science education, University of Tartu. Her extensive experience covers Estonia, Europe and worldwide (Fulbright fellow - University of Iowa, USA). She has a school teaching background, extensive experience in pre/in-service teacher training and been a member of an EC 2004 group publishing a 2004 report on 'Europe needs more Scientists'. Her research covers cognitive learning, relevance, scientific/technological literacy and goals of science education. She has published over 160 articles

Email: miia.rannikmae@ut.ee

Jack Holbrook

Is visiting professor at UT with experience in science education worldwide. He has a school science teaching background, extensive experience in pre/ in-service training workshops and consultancies in a range of countries worldwide. His research covers curriculum development, teacher education and assessment as well supervising PhD students in use-inspired research, scientific literacy, relevance, inquiry-based learning and transdisciplinarity in science education.

Email: jack.holbrook@ut.ee

Regina Soobard

Is an associate professor in science teaching, University of Tartu. She is director for MSc programmes for gymnasium science teacher education. Her main research fields are scientific literacy and assessment within science education. She has experience in creating and piloting research tools, such as those related to student`s attitudes towards science and career choices. Her scientific background is in geography. She is also OECD PISA study science expert in Estonia.

Email: regina.soobard@ut.ee

Tapashi Binte Mahmud Chowdhury

Is working as a researcher at the Centre for Science Education within the Institute of Ecology and Earth Sciences, University of Tartu. She is also teaching science at secondary level. Her doctoral studies emphasised the role of a societal affiliation of science education. Currently she is focusing on conceptualising a trans-disciplinary approach within science education, enabling the inclusion of epistemic orientations in addressing wicked problems within the global society.

Email: tapashib@ut.ee