



Abstract. *Although chemistry-focused socio-scientific issues support the 'relevance' model of chemistry education, the related literature has lacked any systematic review handling them together. For this reason, this research aimed to thematically synthesize the research papers on chemistry-focused socio scientific issues (SSI) from 2008 to 2020 and inferentially evaluate them in terms of the relevance model of chemistry education. After searching international and national well-known databases through relevant keyword patterns (e.g., Pattern 1: socio-scientific issues and chemistry education), 65 research papers were apparent for the systematic review. Then, the authors generated primary and secondary codes for the research papers and then inferentially marked their 'relevance' components. The systematic review indicated variation of research areas (e.g., relevance model of chemistry education) and dominant research foci for different themes (e.g., competencies and related variables for the theme 'aims'; pollution, energy, industry and fabrication-based problems for the theme 'SSI'; organic compounds for the theme 'chemistry concepts'). Further, it revealed that the research papers on chemistry-focused SSI had some shortcomings at handling all components of the relevance model in a balanced way. The current research suggests professionally training teachers about how to integrate chemistry-focused SSI and the relevance model into school chemistry.*

Keywords: *chemistry education, relevance model, socio-scientific issues, systematic review*

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A SYSTEMATIC REVIEW OF THE RESEARCH PAPERS ON CHEMISTRY-FOCUSED SOCIO- SCIENTIFIC ISSUES

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Introduction

Related literature has reported that science education, particularly physics and chemistry, remains unpopular among students (Avargil et al., 2020; Hofstein et al., 2011; Osborne & Dillon, 2008; Stuckey et al., 2013). Much research has also inferred that students are insufficiently interested in science learning. Phrased differently, science subjects do not motivate students to 'doing science' and 'learning of science' (Atasoy et al., 2020; Osborne et al., 2003; Stuckey et al., 2013). Unfortunately, students generally see science and science education as 'irrelevant' for themselves and society (Dillon, 2009; Gilbert, 2006; Stuckey et al., 2013). Therefore, science teachers should make education 'more relevant' in order to stimulate their students' interest in science subjects and/or science learning (Stuckey et al., 2013). Given the foregoing issues, Stuckey et al. (2013) have released the relevance model of science/chemistry education to make science learning relevant. Further, preliminary research papers on the relevance model have reported that socio-scientific issues (SSI) can be used to make science/chemistry learning more relevant (e.g., Eilks et al., 2018; Stuckey & Eilks, 2014; Zowada et al., 2020).

SSI typically contains disagreement and debate among experts, politicians, and citizens to decide the use of science and technology (Albe, 2008; Levinson, 2006; Sadler, 2004, 2009). Because SSI does not have a fixed or universally held point of view, SSI-related explanations and solutions often divide society into different groups (i.e., Crick, 1998; Çalık & Coll, 2012; Çalık et al., 2014). SSI incorporates contentious dilemmas (open-ended, complex, ill-structured issues) and cannot easily be addressed through recall of memorized content knowledge, or simple algorithms (Kolomuç & Çalık, 2019; Sadler, 2004, 2009; Tsai et al., 2019). Thereby, engaging students in SSI and science practices not only develops scientific/chemical literacy but also links societal issues with the nature of science and 21st century skills (Romine et al., 2016; Zeidler, 2015). Therefore, SSI-based instruction requires students to go beyond conceptual understanding (Feierabend & Eilks, 2011; Ke et al., 2020) and improves their critical thinking skills within an informed way or informal reasoning (Semilarski et al., 2019; Zeidler & Nichols, 2009).

Although SSI-based instruction, as an interdisciplinary and multidimensional approach, embraces several subjects (i.e., biology, chemistry,

physics, earth sciences, environmental sciences and so forth), it generally employs a core subject (e.g., chemistry) to frame features and outcomes of student learning. Therefore, this research views chemistry as a focus of SSI (named chemistry-focused SSI) to cultivate chemical literacy and responsible citizenship. Thus, chemistry-focused SSI directly covers conceptual understanding of chemistry and chemical literacy for all students by linking school chemistry with daily life (i.e., Koçak Altundağ, 2018; Ültay & Çalik, 2012; Versprille et al., 2017) and any scientific, technological and environmental development (Gilbert & Treagust, 2009; Mozeika & Bilbokaite, 2010; Zahara & Atun, 2018). Because chemistry plays a milestone in addressing chemistry-focused SSI and finding alternative ways or solutions (Bertozzi et al., 2016; Seery, 2015), students are able to explore chemical problems using conceptual and procedural connections and judge social significance of chemistry on the community or daily life. For example, Eilks et al. (2018) used some chemistry-focused SSI (e.g., musk fragrances in shower gels, low-fat and low-carb diets, doping in professional and leisure sports, bioplastics, Stevia controversy, natural cosmetics, and tattooing) to inform students about responsible citizenship and scientific/chemical literacy. Handling SSI within school chemistry necessitates to learn chemistry concepts and perceive chemistry-related disciplines (e.g., biology, physics, earth sciences, environmental sciences). For example, if they comprehend fundamental acid-base concepts, they are able to critically think about acid rain and its possible effect(s) on the environment. Further, they are able to make an action on how to prevent acid rain. Overall, chemistry-focused SSI and relevance model of chemistry education propose to satisfy students' interest in chemistry and raise their learning motivation and attitudes towards chemistry/science (e.g., Eilks et al., 2018; Stuckey & Eilks, 2014; Stuckey et al., 2013). This, at hand, calls for a systematic review that thematically synthesizes the research papers on chemistry-focused SSI and evaluates them in terms of the relevance model of chemistry education. A lack of such a review paper emerges the need for the current research.

Research Problem

Given the significance of SSI in science education, a few review papers have discussed general trends, similarities and differences for decision making process and/or informal reasoning about SSI (Fang et al., 2019; Garrecht et al., 2018; Jho 2015; Sadler, 2004, 2009; Tekin et al., 2016; Topçu et al., 2014). They stressed that SSI acted as a milestone to make chemistry/science relevant and facilitate informal reasoning and decision-making processes. Of these review papers, only one research (Sadler, 2009) used situated learning as a theoretical framework to review and synthesize SSI as the context of practice. Sadler (2009) deployed situated learning as a powerful analytical lens to explain the influential role(s) of students' educative experiences on their lives. Phrased differently, the use of SSI requires science educators/teachers to re-think about the question "What makes school sciences relevant for students' present and future lives?" (e.g., Sadler, 2004, 2009; Stuckey et al., 2013). Even though SSI has a pivotal role at overcoming students' misperceptions of science education (e.g., lack of relevance) (Gilbert, 2006; Stuckey et al., 2013), none of previous review papers has focused on how the research papers on SSI reflect the relevance in science/chemistry education. In other words, they have not recruited the relevance model of chemistry education as a theoretical framework to analytically illuminate their similarities, differences, and trends.

Furthermore, even though the foregoing review papers have included few chemistry-related SSI (e.g., environmental issues or interdisciplinary problems), they have not directly concentrated on the research papers on chemistry-focused SSI (i.e., road salting, doping in professional and leisure sports, and tattooing) and the 'relevance' model of chemistry education. The gap in related literature calls for the current research to portray the characteristics of chemistry-focused SSI. Hence, the current research may give some insights into chemistry-focused SSI by evaluating the research papers through 'relevance' model of chemistry education (Stuckey et al., 2013). In brief, this research thematically illustrates what is known and what needs to be known for future research on chemistry-focused SSI.

Research Focus

Over 40 years, science educators have argued how to make science education relevant and appeal for students. These debates have resulted in science curriculum reforms and/or movements prioritizing the term 'relevance' in science education (Fensham, 2004; Stuckey et al., 2013). A comprehensive literature review by Stuckey et al. (2013) suggests that making science education 'relevant' at least includes three dimensions: (a) preparing students for



potential careers in science and engineering; (b) understanding scientific phenomena and coping with the challenges in a student's life; and (c) students becoming effective future citizens in the society in which they live (p. 8). Given all issues reported in science education literature, Stuckey et al. (2013) have launched their own model to clarify the term 'relevance' in science education.

The relevance model of chemistry education consists of three dimensions (individual, societal and vocational) and four components (present, future, intrinsic and extrinsic) for each dimension (see Stuckey et al., 2013 for further details and examples). In view of Stuckey et al. (2013), the relevance model develops students' intellectual skills and competencies, awareness and understanding of individual, societal and vocational dimensions (Stuckey et al., 2013). Furthermore, the model highlights two principal questions debated by science educators: (a) how does science education make school science learning relevant for students' present and future lives? and (b) How is school science learning connected to students' out-of-school experiences?

The 'relevance' model can also be used to analyze different curricula (e.g., Salters Advanced Chemistry in the UK) or reforms (e.g., context-based learning) or movements (e.g., SSI). That is, the question "how does any curriculum/reform/movement refer to the 'relevance' model?" may help science educators and curriculum developers decide any new curricular development. Indeed, science educators have recently employed various SSI to respond the foregoing questions and present alternative pedagogical ways to make science learning more relevant. However, none of previous research papers has concentrated on how the research papers on chemistry-focused SSI have supported the relevance model. Further, they have not explored whether there has been any balanced way in promoting different dimensions of the relevance model. These unexplored areas in the related literature emerge the needs of the current research.

Research Significance

Chemistry/science educators have used chemistry-focused SSI to increase learning opportunities and associate school chemistry with societal and real issues (Stuckey et al., 2013). By evaluating the research papers via the 'relevance' model of chemistry education, this research will give some clues about how to make chemistry relevant and popular among students. Hence, the current research will inform chemistry educators, teachers and curriculum developers about trends and unexplored areas in chemistry-focused SSI. Also, handling the research papers within themes (i.e., aims, samples, variables, SSI, dimensions of SSI, chemistry concepts and conclusions) will present a holistic view to unveil their insights and changes over years. Overall, filling an important gap in the related literature makes the current research unique and significant.

Research Aim and Research Questions

This research purposed to thematically synthesize the research papers on chemistry-focused SSI from 2008 to 2020 and inferentially evaluate them in terms of the relevance model of chemistry education. For this purpose, the following research questions guided the current research:

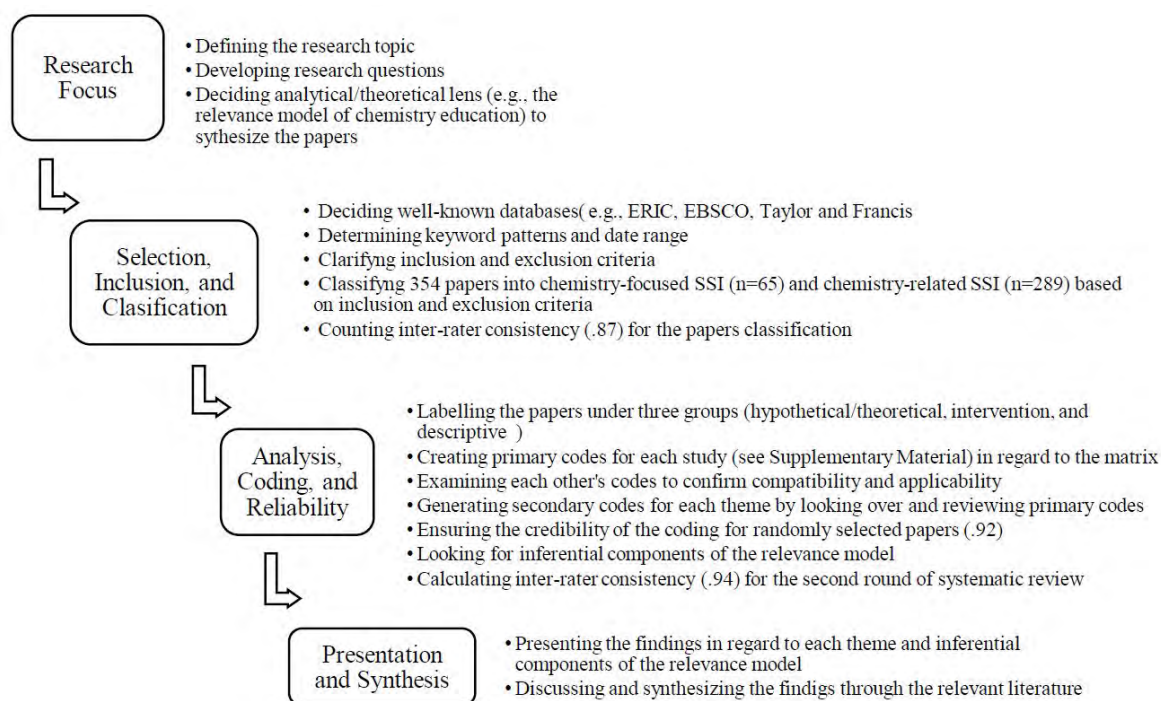
1. What thematic codes do the papers show?
2. How do the papers reflect the relevance model of chemistry education?

Research Methodology

General Background

This research critically and systematically synthesized the research papers on chemistry-focused SSI by creating themes and template (e.g., Bağ & Çalık, 2017; Çalık & Sözbilir, 2014). Thus, it purposed to indicate general trends, similarities and differences of chemistry-focused SSI to disseminate research results and inform stakeholders about further research, policy and practice (Suri & Clarke, 2009) (see Figure 1 for the systematic review procedure).



Figure 1*An Outline of the Systematic Review Procedure*

Data Collection

The authors searched international and national well-known databases (Academic Search Complete, Education Research Complete, ERIC, EBSCO, Springer Link, Taylor & Francis, Wiley Online Library Full Collection, Science Direct, ProQuest Dissertations and Theses Global, Sage Premier 2013, Google Scholar, Scopus, Academia, ResearchGate and e-resources) by means of relevant keyword patterns (Pattern 1: "socio-scientific issues" and "chemistry education"; Pattern 2: "socio-scientific issues" and "science education"; Pattern 3: "controversial issues" and "science education"; Pattern 4: "societal issues" and "science education"; Pattern 5: "daily life" and "chemistry education"; and Pattern 6: "chemical literacy" and "chemistry education") within a certain date range (2008 to 2019) and completed the regular database search on January 25, 2020 ($n: 325$). Further, the authors conducted another database search on December 15, 2020 to cover the research papers ($n: 29$) published in 2020. Then, the authors assigned specific identities (i.e., short titles and authors' names) for each research to refrain from any duplication in databases. Later, given the foci of the current research, 354 research papers were separately classified into chemistry-focused SSI ($n: 65$) and chemistry-related SSI (i.e., interdisciplinary problems/issues) ($n: 289$). In this process, their abstracts were initially read to label them as chemistry-focused/related SSI. When any disagreement or conflict appeared at the classification process, the research papers were deeply examined in regard to inclusion and exclusion criteria.

The authors deployed four criteria for inclusion of chemistry-focused SSI: (1) directly employing chemistry as a driving factor for SSI; (2) handling SSI within any chemistry-focused course(s) or chemistry topic(s) in an integrated science course(s) or science laboratory course(s) or Science, Technology, Engineering, and Mathematics (STEM) education; (3) prioritizing the importance of chemistry in daily life through scientific/chemical literacy; and (4) associating chemistry concepts with other related disciplines or concepts. For example, Çalik and Cobern (2017), who directly exploited 'factors affecting solubility' within the Introductory Chemistry Course, prioritized the importance of chemistry in daily life, i.e., road salting, and associated chemistry with environmental chemistry, environmental education, and ecology. Hence, the authors included this research into the systematic review. In



contrast, the authors excluded the research by Çalik and Coll (2012), which indirectly handled chemistry within global warming and the use of fluoride in municipal water or preceded interdisciplinary issues/problems. Finally, 65 research papers were of interest in the current research (see Appendices at Supplementary Material).

Data Analysis

While grouping the papers as chemistry-related/focused SSI, the authors noticed three research types (*hypothetical/theoretical* research that illustrates any chemistry-focused SSI without any implementation or discusses a sample theoretical framework via the existing literature; *intervention* research that includes the experimental design and/or treatment; and *descriptive* research that explores the participants' views, values, argumentation skills, understanding, perceptions and decision-making processes as well as evaluating lesson plans and/or learning outcomes of chemistry-focused SSI). Thereby, the authors initially labelled the research papers into three groups (i.e., hypothetical/theoretical, intervention and descriptive). To present a detailed and comprehensive systematic review, the authors adapted a matrix (e.g., aims, variables, samples/participants, chemistry concepts, SSI, dimensions of SSI and conclusions) proposed by Çalik et al. (2005). Later, they created primary codes for each research (see Supplementary Material) in regard to the matrix and examined each other's codes to confirm their compatibility and applicability. Then, they generated secondary codes for each theme by inductively reviewing primary codes. Hence, general trends, similarities, differences, and unique features of the research papers were obviously apparent. Moreover, the authors inferentially marked the 'relevance' components of the research papers by carefully re-examining them (see Table S1 for a sample review).

Research Validity and Reliability

To minimize any missing data, two chemistry educators separately classified 354 research papers into two groups (i.e., chemistry-focused SSI and chemistry-related SSI). Inter-rater consistency was found to be .87. Any disagreement was resolved through negotiation. Also, a group of experts (authors and two chemistry educators) independently coded four research papers randomly selected from 65 research papers to ensure the credibility of the coding. Accordingly, inter-rater consistency was found to be .92, which suggests a perfect agreement for the coding (MacPhail et al. 2015; Miles & Huberman, 1994). Later, the authors individually continued the coding procedure and created primary codes for each research (see Supplementary Material). Then, they generated secondary codes by inductively reviewing primary ones. In addition, the authors looked over each other's codes and confirmed their compatibility and applicability. Furthermore, they separately searched the 'relevance' components in the research papers and then checked each other's relevance components. This procedure showed a high consistency value (.94).

Research Results

Thematic Codes for the Research Papers

Theme 'Aims'. As seen from Table S2 (see Supplementary Material), the aims of the research papers consisted of five different codes, whose percentages ranged from 4.6 to 38.5. A high frequency for the first code (see Table S2) may result from common features of SSI that directly trigger or influence such competencies as argumentation, reflective judgment, decision making, and informal reasoning (e.g., Bayram-Jacobs et al., 2019; Karışan et al., 2017; Wiyarsi & Çalik, 2019). The second code may come from mostly preferred common variables, i.e., conceptual understanding, attitude, critical thinking (e.g., Çalik et al., 2015). These papers seem to have provided more evidence about the effect(s) of chemistry-focused SSI on the quality of chemistry education.

The third and fourth codes, which integrated chemistry-focused SSI into chemistry learning/school chemistry, seem to have stimulated students' enthusiasm and interest in chemistry (e.g., Gilbert, 2006; İlhan et al., 2016; Ültay & Çalik, 2012). In fact, these codes also point to responsible citizens in the future (called scientific or chemical literacy). However, the final code (developing measurement tools/instruments regarding chemistry-focused SSI) indicated a challenge to effectively measure and assess their use in chemistry learning. This calls for further research to elicit students' learning curiosity, interest in science/chemistry, higher-order thinking skills and relevant competencies. In a similar vein, orientating participants about potential chemistry/science/STEM careers in their present and future actions can only be accomplished via reliable and valid tools (Stuckey et al., 2013).



Theme 'Variables': As can be seen from Table S3, independent variables covered various teaching interventions (i.e., inquiry-based learning, common knowledge construction model, context-based approach). Also, their dependent variables were varied such as conceptual understanding ($f=4$), critical thinking ($f=3$), environmental literacy ($f=3$), perception/expectation ($f=3$), and attitudes ($f=3$). In brief, dependent variables embraced 'reasoning skills or higher-order thinking skills' ($f: 13$) (e.g., critical thinking, environmental literacy, decision making, argumentation, and chemical/scientific literacy) and affective learning domain(s) ($f: 11$) (e.g., attitude, perception, motivation, self-efficacy and scientific habits of mind). Also, most of them were classified under 'not applicable' since they did not have any independent/dependent variable.

As can be seen from Table S3 (see Supplementary Material), 23 research papers deployed any teaching intervention as an independent variable. Through hands-on and minds-on activities/tasks, they encouraged participants to re-construct their pre-existing knowledge or stimulate their attitudes, interest, perceptions and self-efficacy or informal reasoning skills or argumentation skills (as dependent variables) (e.g., Abels, 2015; Çalik & Cobern, 2017; NRC, 2000). Thus, they may have tried to meet the idea 'education through science' vis-à-vis the one 'education in science' (e.g., Holbrook & Rannikmae, 2007). In other words, constructivist learning theory seems to have affected independent variables (e.g., inquiry-based learning, context-based approach, learning cycle, cooperative learning).

Since most of the dependent variables covered transferable and transformable skills (e.g., critical thinking, environmental literacy, decision making, argumentation, and chemical literacy), the research papers seem to have paid more attention to the demands of the 21st century skills. Meanwhile, although they concentrated on cognitive and affective learning domains (e.g., conceptual understanding, environmental/chemical literacy, attitude, perception, motivation, self-efficacy, and scientific habits of mind) as dependent variables, they have not focused on psychomotor skills that enables students to comprehend the nature and philosophy of science/chemistry (e.g., Irwanto et al., 2019; Karsli Baydere et al., 2020). Interestingly, only one each paper explicitly focused on chemical literacy (Cigdemoglu & Geban, 2015) and scientific literacy (Vogelzan et al., 2020) as a dependent variable. This may result from the scope of scientific literacy (i.e., conceptual understanding, nature of science, scientific habits of mind, scientific attitudes, awareness of the complex relationship(s) among science, technology, society, and environment). Namely, most of the intervention papers seem to have focused on various dimensions of scientific literacy instead of explicitly exploring the effect of any treatment on chemical/scientific literacy level (Roberts & Bybee, 2014; Zeidler, 2015).

Theme 'Samples': As seen from Table S4 (see Supplementary Material), almost half of the research papers selected their participants from 6th-13th grades. A total of 25 (37.9%) research papers involved undergraduate students, while 4 (6.1%) research papers included teachers in their samples. Only one paper (Molinatti & Simonneau, 2015) used scientists as its sample.

The fact that majority of the research papers were conducted with 6th -13th grade students (see Table S4) may stem from a common belief 'lower and upper secondary schools shape students' individual, societal and vocational development.' Further, since undergraduate education and qualified teachers play a pivotal role in chemistry learning/teaching, a significant amount of the research papers may have studied with undergraduate students and teachers (Wan et al., 2013; Karisan et al., 2017). In fact, qualified teachers give much more learning opportunities for their students to empower their learning capacities. For instance, if teachers have relevant competencies/experiences concerning chemistry-focused SSI, they are able to effectively understand and interpret chemistry curriculum and its goals. Thus, such a procedure not only facilitates students' chemistry learning but also promotes chemistry self-efficacy and self-regulated skills for the present and future. Furthermore, the fact that only one paper (Molinatti & Simonneau, 2015) involved scientists as the sample may come from scientists' unwillingness to participate in any research on chemistry-focused SSI. On the other hand, the belief 'scientists always have good reasoning/rational skills or give scientific arguments about chemistry-focused SSI' may have led chemistry/science educators not to study with scientists.

Theme 'SSI': As can be seen from Table S5 (see Supplementary Material), ten codes appeared for the theme 'SSI'. Twenty-one research papers focused on chemicals and environmental pollution, while 20 research papers concentrated on the use of fossil fuels. Further, percentages of the codes 'chemicals in daily life, alternative energy sources, and nutrition' were 11.7, 10.6 and 10.6 respectively, whereas those for the codes 'addictive, food additive, abuse of chemical substances, and chemical in medicine' were 8.5, 4.3, 3.2, and 3.2 respectively.

Although chemistry positively enhances quality of daily life, it engenders some risks. For this reason, the research papers exploited various SSI to make science/chemistry more relevant for their participants. For example, the code 'the use of fossil fuels' might help participants think about how to reduce the effect(s) of global warming.



That is, they might prefer using public transportation or bicycle while going to the school.

The code 'chemicals and environmental pollution' might bridge school science/chemistry to daily life (e.g., Albe, 2008; Holbrook, 1998; Flener-Lovitt, 2014; Versprille et al., 2017) and stimulate participants' interest and attitudes towards chemistry (e.g., Versprille et al., 2017) as well as developing their problem-solving strategies (Mandler et al., 2012). The code 'alternative energy sources' might encourage participants to re-think our consumption habits. Hence, people could think about evidence and content knowledge (e.g., Flener-Lovitt, 2014; Yapıcıoğlu & Aycan, 2018; Karpudewan & Roth, 2016) by weighing and leveraging dimensions of SSI such as economic, environmental, health, social and ethics (Price et al., 2014).

Since daily chemical products may unwittingly endanger human life, the research papers used the code 'chemicals in daily products (i.e., cosmetics, tattooing, soap, shower gels and musk fragrances)' as another interesting SSI. For example, tattoos bring their own risks, e.g., carcinogenic compounds in tattoos (Regensburger et al., 2010), the lack of acceptance in society, tattooing equipment and removing process of tattoos (Stuckey & Eilks, 2014). Risks and benefits of any chemistry-focused SSI require participants to employ critical thinking and argumentation skills (Sadler, 2004; Zeidler & Nichols, 2009). Thus, they can improve open-mindedness and multidimensional thinking while making a decision about any chemistry-focused SSI. Overall, integrating SSI into chemistry learning not only empowers participants' cognitive and affective learning outcomes but also creates a meaningful learning environment. This indicates that chemistry-focused SSI supports informal and formal reasoning abilities without confining chemistry to schools (e.g., Ültay & Çalik, 2012, 2016; Wiyarsi et al., 2020).

Theme 'Chemistry Concepts'. As can be seen from Table S6 (see Supplementary Material), the research papers used chemistry concepts such as organic compounds, macromolecules, inorganic compounds, colloid, acids-bases, and surfactant. Majority of them focused on the organic compounds (e.g., hydrocarbon, amine, alcohol, and ester) through the relevant SSI. Percentages of the research papers handling macromolecules and inorganic compounds were 14.3 and 13.3 respectively, whilst those for the codes 'acids-bases, colloid, thermodynamics, surfactant, and solubility' ranged from 5.7 to 2.9. Also, percentages of the remaining codes fell into 1.9 and 1.0 respectively.

Because organic compounds are mostly used in daily products, the use of organic compounds might be viewed as easily accessible and applicable for chemistry-focused SSI. In addition, the fact that 15 research papers employed macromolecules within chemistry-focused SSI may come from their nutrition and health relations (e.g., fats and carbohydrates). For example, polymers, which are highly economic vis-à-vis natural products, may result in environmental (i.e., a long dissolving period in nature) and health (e.g., cancer) risks. Likewise, main environmental concerns may have directed chemistry/science educators to use other chemistry concepts within chemistry-focused SSI.

The variation in chemistry concepts may come from the nature of chemistry topics. That is, some topics include much more ill-structured, open-ended, and complex issues that call for directly and indirectly relevant chemistry concepts (e.g., organic compounds, macromolecules, inorganic compounds). However, some of them only contain an SSI for relevant chemistry concepts (e.g., solubility for road salting, acids for acid rain). In brief, the research papers seem to have created 'a need-to-know' basis to make abstract chemistry concepts meaningful and emphasize daily-life relevance (e.g., Ültay & Çalik, 2012, 2016; Wiyarsi et al., 2020).

Theme 'Dimensions of SSI'. As seen from Table S7 (see Supplementary Material), nine codes were apparent for this theme. A significant number of the research papers covered societal (23.7%), environmental (23.7%), economic (20.1%) and health (16.0%) dimensions of chemistry-focused SSI. Further, percentages of technological and ethical dimensions fell into 8.8 and 4.1 respectively, whereas those for moral, political, and religious dimensions ranged from 0.5 to 1.5.

Five dominant codes (societal, environmental, economic, health and technological) may result from features of chemistry-focused SSI. For example, biofuel crops (e.g., castor bean, cassava, and corn), which incorporate societal, environmental, economic, and technological dimensions, engage participants in thinking about the need of new agricultural lands. Further, because people with middle and lower incomes mostly struggle with economic issues (e.g., budget, extra cost), they may prioritize economic dimension for their decision-making processes. For example, they may prefer cheap chemicals (e.g., sodium chloride) in snow removal to expensive alternative chemicals. Even though SSI broadly stresses ethics, moral reasoning and emotional development, few research papers handled these dimensions within chemistry-focused SSI. In a similar vein, only one paper (Rahem, 2018) examined religious dimension through the medical use of alcohol (permissibility or 'halal'-ness). This may stem from dogmatic feature of religion. Likewise, the fact that only three papers (Pratiwi et al., 2016; Stuckey & Eilks 2014; Gulacar et al., 2020) focused on the political dimension may come from a belief 'political issues cannot be easily changed, or politicians are not easily accessible.'



Theme ‘Conclusions’: As seen from Table S8 (see Supplementary Material), four different codes appeared. Most of the research papers fell into the first two codes: Fruitfulness of chemistry-focused SSI to explore related competencies/factors (41.5%) and positive improvement/change in learning outcomes (35.4%). Further, percentages of the remaining codes were 18.5 and 4.6 respectively.

As seen from Table S8, two-fifth of them concluded that chemistry-focused SSI was fruitful to explore related competencies/factors (e.g., argumentation skills, decision making skills). Hence, chemistry-focused SSI allows participants to possess multidimensional thinking skills (Acar et al., 2010; Cavagnetto, 2010; Evagorou & Osborne, 2013; Sadler, 2004, 2009) and behave as responsible citizens (Çapkınoğlu & Yılmaz, 2018; Stuckey et al., 2013). Moreover, positive improvements/changes in chemistry learning (e.g., critical thinking skills, argumentation skills, scientific literacy) may come from student-centered approaches/strategies (i.e., inquiry-based learning, leaning cycles, experimental scientific practices) in chemistry classes (Aydeniz et al., 2012; Herrenkohl & Cornelius, 2013; Memiş, 2014).

Twelve research papers, which reported good learning practices or measurement tools (i.e., lesson plans, instruments), illustrated why the use of chemistry-focused SSI was important for chemistry learning/classes. Thereby, given these good learning practices or measurement tools, chemistry teachers/educators may get some insights about the question ‘how to handle chemistry-focused SSI within chemistry learning/school chemistry’. Interestingly, only three research papers (Eilks et al., 2018; Juntunen & Aksela, 2014; Marks & Eilks, 2009) explicitly associated chemistry-focused SSI to other aspects or disciplines (e.g., ESD and curriculum model). This may result from complex nature of interdisciplinary research (e.g., finding enough budget, working with different experts, and intertwining different content knowledge/disciplines with chemistry). On the other hand, this may come from the focus of the current research, which excluded chemistry-related SSI emphasizing interdisciplinary problems/issues.

Inferential Components for the Relevance Model of Chemistry Education

As seen from Table S9, all of the research papers referred to the future-intrinsic and extrinsic components of individual and societal dimensions. This may result from the goal of chemistry education, which is to educate students to become a responsible citizen in the future. Further, this may come from features of chemistry-focused SSI that confront students with ill-structured issues and drive them to use their own transferable and transformable skills. These skills/competencies not only facilitate their individual lives in future to solve real-world problems (the future-intrinsic component of individual dimension) (Stuckey et al., 2013), but also promote their own interest in societal discourse (the future-intrinsic component of societal dimension). Because chemistry-focused SSI also advocates multidimensional thinking and scientific habits of mind (i.e., open-mindedness, skepticism), it employs skills for coping with personal life in the future and activates participants’ responsibilities and solidarities with others (the future-extrinsic component of individual dimension). Further, it cultivates them to behave as responsible citizens in the society (the future-extrinsic component of societal dimension) (Stuckey et al., 2013).

Most of the research papers handled the present-intrinsic component of individual dimension ($f: 62; 95.4\%$) and present-intrinsic and extrinsic components of societal dimension ($f: 54; 83.1\%$). A high proportion in the present-intrinsic component of individual dimension may stem from a ‘need-to-know’ basis (e.g., Ültay & Çalik, 2012), which individually satisfies students’ learning curiosity and stimulates their interest in chemistry/science (Stuckey et al., 2013). In other words, because SSI acts as an actual context to see the relevance of chemistry in daily life (Flener-Lovitt, 2014; Gilbert, 2006; Parchmann et al., 2006), the research papers may have purposed to equip the participants with personal and societal life skills (Feierabend & Eilks, 2011; Stuckey et al., 2013) and meet their individual learning curiosity/interest in the present. Likewise, through the present-intrinsic and extrinsic components of societal dimension, the research papers seem to have promoted the participants to find their own places in society (e.g., becoming a scientifically literate person) and learn how to behave in society (Stuckey et al., 2013). For example, students are able to defend their own decisions/arguments about any regulation of the use of shale gas (Bayram et al., 2019; Mollinati & Simmoneu, 2015). Their arguments/decisions may lead them to find their own places in society and learn how to defend their own views of chemistry-focused SSI (Stuckey et al., 2013).

The research papers generally dealt with the present-intrinsic and extrinsic components of vocational dimension. In fact, these ratios were relatively low as compared to other dimensions of the relevance model. This means that the research papers have had some difficulties at embedding vocational dimension and related components within science/chemistry learning. Given all components of vocational dimension, the research papers reflected the present-intrinsic and extrinsic components rather than the future ones. This may result from the nature of the



present components of vocational dimension. That is, the researchers may have found these components more applicable and researchable than the future-ones. Indeed, the future components of vocational dimension generally request a long-term research to examine the targeted/expected goals. Moreover, any research, which recruits any regular course (e.g., introductory chemistry course) (Çalik & Cobern, 2017), extrinsically fosters participants' advanced science learning and enhances the quality of their next education. Thus, the research papers may have illuminated the present-extrinsic component of vocational dimension. Similarly, the research papers exploring good practices for science/chemistry learning may have stimulated participants' orientation about potential chemistry/science/STEM careers (the present-intrinsic component of vocational dimension) (Stuckey et al., 2013). For instance, using acid rain as an SSI may foster participants to learn how chemists or chemistry-related occupations can minimize the impact(s) of acid rain on chlorosis/corrosion and acidity of ocean. Indeed, if participants feel themselves comfortable for chemistry learning and achieve the targeted goals of chemistry education, they are able to continue their chemistry careers.

The present-extrinsic component of individual dimension, which possessed the lowest percentage, maybe a result of any research concern. For instance, the use of extra marks and/or credits (as the present-extrinsic component of individual dimension) may extrinsically manipulate the research results. Therefore, the researchers may have disregarded this component in their papers. Nevertheless, the foregoing results may come from limited research directly following the relevance model of chemistry education.

Conclusions and Implications

The systematic review indicated variation of research areas (e.g., relevance model of chemistry education) and dominant research foci with different themes (e.g., competencies and related variables for the theme 'aims'; students (6th-13th grades) and undergraduate students for the theme 'samples'; pollution, energy, industry and fabrication-based problems for the theme 'SSI'; organic compounds for the theme 'chemistry concepts'). As compared with earlier review papers, the current research showed that chemistry/science educators preferred more chemistry-focused SSI over time. This means that chemistry-focused SSI has invaluable learning opportunities to make chemistry learning and chemical literacy sustainable. Since the research papers reported promising results/conclusions about associating school chemistry with societal/real-life issues, the current research justified the significance of the 'relevance' model at developing responsible citizenship and increasing students' interest in learning chemistry. However, the research papers somewhat illuminated individual (e.g., satisfying curiosity and interest in the present, and skills for coping with personal life in the future), societal (e.g., behaving as a responsible citizen, and promoting one's own interest in societal discourse in the future) and vocational (e.g., orientation about potential careers in the present) dimensions of the relevance model. Given these results, it can be concluded that they have still had some shortcomings at reflecting and supporting all components of the relevance model in a balanced way. For this reason, future research should make more emphasis on the future components of the relevance model (e.g., the future-intrinsic and extrinsic components of vocational dimension). Moreover, further research ought to illustrate how to integrate all components of the 'relevance' model into school chemistry in a balanced way.

Because chemistry-focused SSI has a pivotal role at developing the 21st century skills, future research should measure and explore its impacts on chemistry learning and/or chemistry careers. Further research should also focus on psychomotor skills that play a significant role in chemistry learning. Moreover, given widespread use of educational technologies, future research ought to improve technology-integrated instructions/interventions for chemistry-focused SSI and test their possible effects on learning outcomes. Furthermore, reliable and valid tools should be developed to predict participants' orientation about potential chemistry/science/STEM careers. Given little research discovering scientists' views of chemistry-focused SSI, further research should focus on their views, attitudes, perceptions, and arguments of ill-structured and open-ended issues. Moreover, because teachers act as the principal factor to achieve the goals of chemistry learning, future research ought to professionally train them about how to integrate chemistry-focused SSI and the relevance model into school chemistry. For example, teachers may be educated about creating their own concept cartoons of chemistry-focused SSI.

Research Limitations

Even though SSI, as an interdisciplinary and multidimensional approach, covers chemistry, biology, earth sciences and so on, this research only focused on the research papers on chemistry-focused SSI. Hence, review-



ing chemistry-focused SSI may be seen as the first limitation of the research. Also, refining the research papers within the period of 2008-2020 (as the recency criterion) may be viewed as the second limitation of the current research. Given the word limit of the journal, the current research, as part of an extensive international project, only reported some themes and excluded the research papers on chemistry-related SSI. This may be considered as the third limitation of the research.

Acknowledgements

The authors would like to thank Dr. Wipsar Sunu Brams Dwandaru and Professor Eli Rohaeti from Yogyakarta State University, Indonesia and Professor Justin Dillon from University of Exeter, UK for their invaluable assistance at language polishing and improving the quality of the paper.

Declaration of Interest

Authors declare no competing interest.

Supplementary Material

Please visit the link https://www.researchgate.net/publication/350735272_JBSE_SM for all tables and appendices.

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Received: February 01, 2021

Accepted: May 12, 2021

Cite as: Çalik, M., & Wiyarsi, A. (2021). A systematic review of the research papers on chemistry-focused socio-scientific issues. *Journal of Baltic Science Education*, 20(3), 360-372. <https://doi.org/10.33225/jbse/21.20.360>

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