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Promoting Students' Scientific Habits of Mind and Chemical Literacy Using the Context of Socio-Scientific Issues on the Inquiry Learning

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This quasi-experimental study used a pre-/posttest design to investigate student's scientific habits of mind (SHOM) and chemical literacy. There were 32 students of the 11th grade selected for the experimental and control class. They were taken by random sampling. The experimental class applied inquiry learning via Predict-Observe-Explain-Extend (POEEd) using the socio-scientific issue (SSI) context, while the control class used a scientific approach that addressed the Indonesian national curriculum. The Acid-Base Chemical Literacy Test (A-BCLT) consisted of 19 items that used four contexts. Argumentative question added on each context. The other instrument was the SHOM scale in the SSI context. The scale consisted of 20 items in seven factors of SHOM. A group of experts looked at both instruments to ensure content validity. Then, the empirical test showed that both instruments have good reliability. MANOVA as the inferential statistic technique was used to analyze the differences among the group. The results showed that there was a significant difference in SHOM and students' chemical literacy simultaneously. However, there was only a significant difference in students' chemical literacy on separate analyses. Students have a better scientific argument in the case of acid rain as SSI, but it was less good for consumption of ulcer medicine for fasting people. Meanwhile, for SHOM, students have better thinking in open-mindedness and objectivity factors but less on curiosity. Some of the interesting findings and their implications are discussed in this study. The integration of SSI in chemistry learning is important. It is meaningful in promoting students' thinking skills to become responsible citizens in the future.

Keywords: acid-base, chemical literacy, context-based learning, inquiry based-learning, scientific habits of mind, socio-scientific issues

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INTRODUCTION

The development of science and technology exposes everyone to a life that is always developing with complex problems. These problems are related to aspects of physical or non-physical environmental conditions, health quality, or social and economic life. This condition requires everyone to be wiser in making decisions in life. Chemistry education as part of science education is considered to be one of the solutions to support the young generation to be responsible citizens caring toward environmental and community's problems in where they live (Sjostrom et al., 2015). Consequently, chemistry teachers should make chemistry learning relevant for students' life (e.g., Gilbert, 2006; Stuckey et al., 2013).

Using educational topics adopted from issues of daily life and society, such as health, food, and fuel (e.g., Broman and Parchmann, 2014), enables students to recognize the importance of chemistry in understanding scientific phenomena and technological problems (Gilbert, 2006). Furthermore, socio-scientific issues (SSIs) were reported as a potential topic to make chemistry learning relevant (e.g., Eilks et al., 2018; Zowada et al., 2020) since it helped students to connect the scientific concepts and social problems in their daily lives (Capkinoglu et al., 2019). Previous studies showed that bringing SSI in science learning improved students' decision making (Rizal et al., 2017; Christenson et al., 2014, and students' awareness toward environmental and daily problems (e.g., Juntunen and Aksela, 2013; Korolija et al., 2015; Drury et al., 2016; Shamuganathan and Karpudewan, 2017).

Socio-scientific issuesas a controversial issue in society, related to science, morals, and ethics (Zeidler, 2003; Sadler, 2004), has become a potential topic to attract students' attention in chemistry learning. Thus, the use of SSIs in the classroom is the potential for enhancing students' thinking and provide opportunities for the development of a responsible citizenry capable of applying science. Through SSIs, reasoning that is built on the fundamental of attitudes/habits of thinking will offer a manner for students to evaluate their thinking toward different contexts of problems (Zeidler et al., 2013). Hence, SSIs give more challenges in promoting a student to think like scientists or have the scientific habit of mind (SHOM). The present study proposes that engaging SHOM within SSIs would benefit from a deeper understanding of how student teachers think.

On the other hand, Çalik and Coll (2012) developed the SHOM scale using SSIs that are commonly faced by global communities such as global warming, vaccination, and climate change. Further studies indicated the implementation of this scale for measuring SHOM conducted with varieties participants. Çalik et al. (2014) investigated elementary student teachers' SHOM and showed that SHOM was affected by students' grade and study programs (i.e., teacher education for science, social science, mathematics, and primary teacher education). Moreover, SHOM handling SSI was taken as the dependent variable in two experimental studies (Çalik and Cobern, 2017; Çalik and Karataş, 2019). The studies concluded that science teachers' SHOM was improving during active learning. Interestingly, there have not similar study that conducted for high school students.

Notably, exploring students' SHOM via SSIs supports their ability in making an appropriate decision toward SSIs (i.e., road salting, tattooing, mass vaccination, climate change, fossil fuels, use of lead, and acid rain) within considering any facts and evidence in promoting chemical literacy (e.g., Cigdemoglu and Geban, 2015; Blonder et al., 2016; Çalik and Cobern, 2017; Eilks et al., 2018; Zowada et al., 2018). Chemical literacy ability helps students become more critical, analytical, and creative in ways that support the development of 21st-century skills. This ability helps students to grow as responsible citizens in the future. However, students' chemical literacy still needs to be improved (e.g., Dewi et al., 2019; Eny and Wiyarsi, 2019; Yustin and Wiyarsi, 2019; Wiyarsi et al., 2020). Going forth, schools should offer any proper learning environment in urging students' SHOM and improving their chemical literacy.

Phrased differently, choosing a learning approach should pay attention to the characteristics of the topics/concepts and the expected learning outcomes. For example, constructivist-based learning as inquiry and context-based learning is an appropriate approach for increasing students' transferable skills and higher-order thinking skills (HOTS). Several studies used inquiry learning for chemistry learning to improve SHOM (Çalik and Cobern, 2017), argumentation (Grooms et al., 2014), and students' attitude (Rahayu et al., 2018). Moreover, other studies have combined inquiry learning with SSI-based instruction that affects students' perception of the learning environment (Rahayu et al., 2019) and students' learning motivation (Yuliastini et al., 2018). Integrating SSI into inquiry learning should be extended to appropriate topics of chemistry.

Moreover, for the acid-base topic, many SSIs are founded that relate to this topic: for instance, acid rain (Ismail and Wiyarsi, 2020), drinking water (Mandler et al., 2012), coral reefs (Wiyarsi and Çalik, 2019), soap and detergent (Broman et al., 2018), and carbonated/sodas beverages (Grooms et al., 2014; Cahyarini et al., 2016). The use of SSI in acid-bases learning initiates students' interest in learning. Constructivistically, students will build knowledge, share knowledge and apply their knowledge to solve problems related to SSI. That is, it will overcome some problems in acid-base learning, such as alternative conception (Costu et al., 2009; Ültay and Çalik, 2016), less on high order thinking skill (Cooper et al., 2016), and low perception toward meaningful topic to daily life (Ültay and Çalik, 2016). Student awareness of environmental and community problems could be promoted through chemistry education and help them become more responsible citizens.

Socio-scientific Issue and Students' Chemical Literacy

The attainment of scientific literacy for all students is the main goal of the science of education. Chemistry education as part of science conveys a similar framework since the context of chemistry toward daily life situations provides the students with the opportunity to show their chemical literacy skills. The chemical literacy framework is derived from scientific literacy that embodies scientific ideas, concepts, and practices within and across many scientific disciplines (Shwartz et al., 2006). Furthermore, Shwartz et al. (2006) proposed four aspects of chemical literacy, namely, chemistry content knowledge, chemistry in context, higher-order learning skills, and affective aspects.

The chemistry content knowledge describes how a chemically literate student should understand the (a) general chemical ideas, such as through scientific investigations, generalization of findings, and the use of knowledge to explain a phenomenon;

and (b) key ideas or the characteristics of chemistry, including how the students can explain the macroscopic level of chemistry. Chemistry in context explains real-life situations involving chemistry and technology, and such students should be able to use chemistry knowledge for explaining everyday situations from several points of view (e.g., health, environmental), describe daily-life chemistry, and participate in social arguments regarding chemistry-related issues. The students' higher-order learning skills involving decision-making and reasoning abilities. The affective aspects describe the students' interest in learning chemistry. Students give a response toward scientific issues that represent their interest in these issues, are supportive of the scientific approach, and have a sense of responsibility toward the situation. Such skills are essential to the interplay of science and technology with society, ecology, economy, and with students' desires, needs, and interests (Fensham, 2002; Marks and Eilks, 2009).

Witte and Beers (2003) explained that the chemical literacy assessment is carried out by measure students' ability to use and dealing with given information in a chemistry problem and students' ability to use chemistry knowledge and skills to comprehend information regarding an everyday problem. These skills are understanding given information, the capacity to select needed information from the text, the capacity to alter given information to another form, and the capacity to assess information from the acceptability or plausibility aspect. Besides, Cigdemoglu and Geban (2015) proposed that higher-order learning skills could be examined by evaluate pro-con of and debates such a scientific problem in society. This problem is such as the performance of engine car that possibly makes environmental problems.

Phrased differently, most students feel that chemistry lessons were not important for future life unless they ended up working in a profession related to the chemistry field. This problem comes from the lack of relevance of chemistry/science (Gilbert, 2006). Consequently, chemistry learning should use context that is familiar with students' life if possible to engage all students. Having real-life context gives students the opportunity to show their literacy skills. The context in this sense can be an industrial process, an environmental issue, an everyday life problem, or even a scientific problem in the community.

Socio-scientific issue as a controversial issue can be used as a context of chemistry learning. Because of the multi-dimensional nature of SSIs (e.g., they typically have economic, political, religious, ethical, and environmental dimensions (e.g., Çalik and Coll, 2012; Zeidler et al., 2013), students cannot easily solve these SSIs through traditional learning approaches—the recall of memorized content/factual knowledge or the application of simple algorithms (Sadler, 2004, 2009). Instead, exploring SSIs calls for negotiation of scientific concepts, principles, and practices in the context of open questions (Kolstø, 2001; Sadler, 2009), which exposes students to "science in the making" or "knowledge in the making." Additionally, many SSIs concern topics that scientists are currently working on and are engaged in debate. This suggests that SSIs and nature of science (NOS) are interrelated (e.g., Çalik and Coll, 2012), in that engaging students in SSI debates helps them to see how scientists make knowledge claims, and how scientists use and develop evidence to support tentative/initial conclusions and test their hypotheses or explanations of data (i.e., s Laugksch, 2000; Dillon, 2009).

Discussion and debate of SSIs help develop student' critical thinking in identifying and analyzing scientific information. SSI-based instruction engages students with an interesting scientific problem and trains them in making decisions toward a social problem that has a moral implication on scientific context. On the other hand, taking arguments in the context of SSIs is a component of scientific literacy that helps to involve students in the practices of arguments (Khishfe et al., 2017). Therefore, using SSIs in chemistry context-based learning could improve students' chemical literacy.

Socio-scientific Issue and Students' Scientific Habits of Mind

Socio-scientific issues are understood as controversial social issues with conceptual and/or procedural links to science. The issues are open-ended problems without clear-cut solutions; in fact, they tend to have multiple plausible solutions. These solutions can be informed by scientific principles, theories, and data, but the solutions cannot be fully determined by scientific considerations. The SSIs affect several fields of life, such as economic, social, and education areas that are useful to encourage the development of sustainability of a country. Thus, case-based SSIs cultivate habits of mind that promote ethical awareness and commitment to issue resolution and the moral sensitivity to hear dissenting voices (Zeidler et al., 2005). SSIs help students in examining how power and authority are embedded in scientific enterprises. Moreover, arguments can be used as a basis to cultivate decision-making in the context of SSIs, which helps in the development of scientifically literate students (Khishfe et al., 2017). That is, engaging in debate about SSI would benefit from a deeper understanding of how scientists think called SHOM.

Scientific habits of mind is a useful way to characterize how scientists think (Gauld, 1982, 2005). Furthermore, Çalik and Coll (2012) summarized the components of SHOM by Gauld, and key features about decision making and argument about SSI that found the overlap among them: open-mindedness (OM); Rationality (RA); Objectivity (OB), such as evidence, bias, and scrutiny; mistrust of arguments (trustworthiness or credibility); skepticism (SC), i.e., asking critical or epistemological questions, uncertainty, and critical thinking; and suspension of belief (SOB). Thus, there are seven aspects of exploring SHOM via SSI: OM (have an open mind to accept new ideas), SC (have a critical judgment of a certain thing, even if it is a brand new), RA (have rationally thought by drawing good reason through logical arguments), OB (reduce idiosyncratic contributions of investigators to the minimum), mistrust of arguments from authority/MTA (do not assume authority figures are correct, merely because they hold positions of authority), SOB (not in rush and too fast to conclude), and curiosity/CU (the desire to learn and the curiosity of someone who learns) (Gauld, 2005; Çalik and Coll, 2012; Çalik et al., 2014). All these habits of thinking will develop better if students do not only think conceptually but are also faced with complex scientific problems. SSIs are a potential topic for investigating students' SHOM.

Given the importance of SSI in facilitating students' SHOM, scales to measure students via SSIs as the context for thinking have been developed (Çalik and Coll, 2012; Wiyarsi and Çalik, 2019). For instance, they used SSIs like alternative treatment and vaccination to investigate mistrust of the argument from the authority, issues about rainforests and biodiversity, and overhead power lines to explore rationality, using issues about nutrition, energy sources, and climate change to measure open-mindedness. In addition, previous studies showed that using SSIs as a way to examine students' SHOM became a useful study for exploring students' decision-making about SSIs (e.g., Çalik et al., 2014; Çalik and Karataş, 2019).

Predict-Observe-Explain-Extend Strategy

Predict-explain-observe (POE) is a learning strategy in the inquiry framework. The POE strategy identifies students' understanding of science concepts and promotes student discussion in the learning process (Liew and Treagust, 1995; Kearney et al., 2001). In the POE strategy, students predict the outcome of an event or situation and indicate the reasons for their predictions. Then, they observe the event or situation and explain any discrepancy between their predictions and observations (White and Gunstone, 1992; Liew and Treagust, 1995; Kearney et al., 2001). POE strategy in chemistry learning improves students' conceptual understanding (Coştu et al., 2012; Karamustafaoğlu and Naaman, 2015; Cengiz, 2018); promote students' activities (Güngör and Özkan, 2020); and reduce students' misconception (Kibirige et al., 2014).

This POE strategy was developed by previous researchers by adding explain step after the predict step. The new strategy becomes Predict-Explain-Predict-Explain (PEOE), which can analyze students' conceptual change well (Rickey and Stacey, 2015; Çalik and Cobern, 2017) as well as student learning achievement (Ajayi et al., 2015). Another development of POE was carried out by Hilario (2015) by adding an explore step and become Predict-Observe-Explain-Explore (POEE). The POEE strategy is applied to general chemistry courses to improve students' attitudes and conceptual understanding. The explore step aims to develop basic chemical research/experiment topics related to various aspects of life.

This current study develops the POE strategy by adding Extend (Ed) step in the last become Predict-Observe-Explain-Extend (POEEd). The "Extend" step in this strategy was aimed to discuss the SSI related to the chemistry concept deeply. In the first step, students start their learning by analyzing social problems from a scientific point of view. Then, students predict the link between the concepts and the presented SSI. At the observation step, students collect the data through a literature study, observation, experimentation, and discussion to answer their predictions. Furthermore, at the explain step, students explain the accuracy of predictions with strong evidence support. Through all of the steps, the components of students' SHOM are trained to become literate people toward scientific problems in society.

Research Questions

This study will extend the use of SSIs in acid-base inquiry learning to enhance students' learning outcomes. The following research question guided this study:

1. Is there any significant difference between students' SHOM and chemical literacy in the experimental class (that learns in the inquiry learning with SSI context) and in the control class?
2. Is there any significant difference between students' SHOM before and after the inquiry learning with SSI context on the acid-base topic?
3. Is there any significant difference in students' chemical literacy before and after the inquiry learning with SSI context on the acid-base topic?

MATERIALS AND METHODS

Research Design

This study used a quasi-experimental method with a pre-/posttest design. One group as the experimental class applied inquiry learning using the SSI context. Meanwhile, another group as a control class used a scientific approach that addressed the Indonesian national curriculum. Students' SHOM and chemical literacy were measured before and after the treatment.

Research Sample

There were 32 students of the 11th grade both for experimental and control classes. A total of 64 students were taken by cluster random sampling technique from one senior high school in Yogyakarta city, Indonesia. The same teacher taught both classes with students that had the same socio-economic background, an age range of 16–17-year-olds, and equal prior knowledge about chemistry.

Teaching Intervention

The teaching intervention was conducted for six meetings of 90 min each. The activity covered four topics: the theory of acid-base, the acid-base indicator, the power of hydrogen (pH) of acid, and the power of hydrogen (pH) of base. The experimental class worked in small groups (4–5 students) and followed inquiry learning using the SSI context with the POEEd (Predict-Observation-Explain-Extend) strategy. The SSIs were integrated into the POEEd strategy and covered the use of borax in food, acid rain, coral reefs, cyanide acid in "gadung" (*Dioscorea hispida*), and the habits of chewing betel leaf. The SSI was used as a learning starting point on the predict step and discussed the SSI dimension deeply during the last step. The control class applied a scientific approach that addressed the Indonesian national curriculum. The Scientific approach has five features, namely, observing, asking, collecting, associating, and communicating. **Table 1** described the sample of different learning conditions in the experimental and control classes on the pH of the base.

TABLE 1 | An outline of the fourth lesson about pH of base.

Experimental class	Control class
Predict step. Students started their learning by understanding the habits of women in chewing betel (as local SSI) in the village. Students arranged their questions and predictions about the advantages and disadvantages of chewing betel leaf, the composition of the material in chewing betel leaf related to the acid-base concept, how to determine the pH, how to identify their characteristics also are they permitted for daily food, and how a community should to respond this issue.	Observing feature. The students observed the data about the pH of the base of several compounds that was presented by the teacher.
Observe step. Students in their groups undertook several activities, such as searching the relevant literature, discussing, and brainstorming with others. The main goal was to collect information as much as they could.	Asking feature. The students asked questions based on the presented data.
Explain step. Students explained many questions that have been arranged in the prediction step. Their explanation was based on the fact from the related literature. Students also compared their predictions and the appropriate answer.	Collecting and Associating feature. The students discussed in a group to solve the problem of calculating the pH of the base and determining the pH of the strong base. They used related literature.
Extend step. At the last step, the students develop critical thinking and make arguments and decisions related to habits of chewing betel leaf from the lens of SSI dimensions. Students choose the SSI dimension independently with their group. There were also activities to solve the pH of base problems to the enriching of the students' understanding. After all the group completed their tasks, two students of the two groups presented their conclusion and class were discussions carried out. The teacher provided feedback.	Communicating feature. Then, selected students presented their work in front of the class. The class discussion was conducted. The teacher gave more explanations to increase students' understanding. Students received much homework (in the form of questions).

Data Collection Tools

The Acid-Base Chemical Literacy Test (A-BCLT) consists of 19 items. The items cover the acid-base theory, the acid-base indicator, the degree of acid-base, and are followed by one argumentation question toward SSI for each context. There are four SSI in four contexts that are used to A-BLCT development. They are the acid rain in the environmental context (item number 1–6); the ulcer medicine in the health context (7–11); the borax in the food context (12–15), and the glass cleaner in the context of daily life product (16–19) (see **Supplementary Material A**). Then, the higher-order learning skills, as another aspect of chemical literacy, were measured through skills in identifying scientific information (items number 2–3, 5, 7–8), relating scientific information (12–14, 16–18), and analyzing scientific information (1, 4, 9–10). To ensure the content validity, a group of experts look at the initial A-BCLT, and based on their suggestions, the test has been revised. Then, A-BCLT is administered to 60 students out of the research samples to examine the construct validity. The empirical test showed that all items of A-BCLT were valid, and the reliability value achieved was 0.73 (see the **Supplementary Material** for completed data). The A-BCLT was calculated with 38 points as the maximum score and zero as the minimum score.

The other instrument is the SHOM scale in the SSI context. The scale consists of 31 items in seven factors of SHOM adapted from Çalik and Coll (2012). The adapted scale covers several SSIs, namely, radiation, overhead power lines, alternative medical treatment, food additives, vaccination, and climate change. There are three types of adaptation include adaption with change the items with more familiar SSI in the Indonesian context (5 items); adjustment of contexts (2 items) and just for language translation. A group of experts examined the scale to ensure content validation, especially for new items. Then, revalidated the scale was conducted, with 360 senior high school students. The result showed that the SHOM scale with 20 items had good reliability (r = 0.76). Items were distributed into seven factors of SHOM: mistrust of argument from authority/MTA (item number 1–2); open-mindedness/OM (3–6); skepticism/SC (7–9); rationality/RA (10–11); suspension of belief/SOB (12–15); objectivity/OB (16–18); and curiosity/CU (19–20). See **Supplementary Material B** for a detailed SHOM scale. The scale had two scoring techniques: positive (1–4) and negative (4–1).

Data Analysis Techniques

Multivariate Analysis of Variance (MANOVA) as the inferential statistic technique was used to analyze the differences among the groups in students' SHOM and chemical literacy. The pre-requisite of the MANOVA has been calculated. The data have normal distribution based on the Shapiro Wilk test with $p > 0.146$ for chemical literacy of experimental class and $p > 0.051$ for control class, also $p > 0.882$ for SHOM of experimental class and $p > 0.530$ for control class. The Levene test ($p > 0.64$) showed that the data are homogeneity and the Box's M test indicated that the data do not have homogeneity of matrix variance-covariance ($p = 0.036$). It means that the Pillai Trace test of MANOVA is the appropriate one. The paired t-test was used for analyzing the differences among pre and post-data in the experimental and control class. Descriptive statistics were addressed to present the mean scores of students' SHOM and chemical literacy and also calculated the frequencies and percentages of coding for students' argumentation toward SSI (item number 6, 11, 15, and 19 of A-BCLT).

RESULTS

The Differences of Students' SHOM and Chemical Literacy in the Inquiry Learning Using SSI Context and Scientific Learning Approach

Based on **Table 2**, the mean scores of students' SHOM and chemical literacy (both the experimental and control groups) were increased. Students that learned in the inquiry learning using SSI had better SHOM's score in the last learning. Also

TABLE 2 | Descriptive statistic of students' SHOM and chemical literacy.

Parameter	Students' SHOM				Students' chemical literacy			
	Experimental group		Control group		Experimental group		Control group	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Number of students	32	32	32	32	32	32	32	32
Mean Score	56.843	69.656	55.531	57.968	8.687	32.750	6.656	26.312
Std. Dev.	3.785	4.490	4.227	4.755	4.934	4.536	5.039	6.860

for chemical literacy, the post-test score of the experimental group indicated better achievement. Furthermore, the result of MANOVA analysis (see **Table 3**) showed that there was a significant difference in students' SHOM and chemical literacy between experimental and control groups with $p = 0.000$ and had an effective contribution of 32.3%. Test of between-subjects effects showed that there was a difference for students "chemical literacy ($p = 0.000$ with an effective contribution of 32.2%), and there was no significant difference for the SHOM studies" ($p = 0.663$). Furthermore, the effect size also was measured by the value Cohen d (Cohen, 1988). The d value was 1.126 which means it has a size effect value of 0.232 for chemical literacy. This value indicated a small effect size (Cohen, 1988). Meanwhile, the d value for SHOM was 0.025 which has zero (0) effect size. The result was relevant to the calculation of the effect of treatment based on the partial eta square value of MANOVA where the inquiry learning using SSI context does not partially affect students' SHOM.

The Differences of Students' SHOM Before and After the Implementation of the Inquiry Learning Using SSI Context

The next analysis was focused on the data for the experimental group to see the effect of inquiry learning using the SSI context in greater depth. The d value for SHOM was 2.94, which has an effect size of 0.662 (Cohen, 1988). Thus, it can be concluded that the inquiry learning using the SSI context has a moderate effect on students' SHOM in the experimental class. **Table 4** showed that there was a significant difference in students' SHOM before and after the teaching intervention. Besides, the deep analysis

TABLE 3 | Result of MANOVA test.

Test	Pillai trace	Test of between subject effects	
		Students' SHOM	Students' chemical literacy
F	14.537	0.191	29.499
P*	0.000	0.663	0.000
Partial Eta Squared	0.323	0.003	0.322
Conclusion(*)	Significantly Different	No Difference	Significantly Different

(*) Computed using alpha: 0.05.

TABLE 4 | Paired *t*-Test for SHOM in inquiry learning using the SSI context.

	Mean	SD	df	*t*-value	*P**	Conclusion (*)
Pre-Post	−2.812	4.475	31	−3.555	0.001	Significantly Different

(*) Computed using alpha: 0.05.

TABLE 5 | Mean score of SHOM's aspect in the inquiry learning using the SSI context.

Factor	Mean						
	MTA	SOB	SC	RA	OM	OB	CU
Pre	2.844	2.406	2.773	3.063	2.948	3.344	2.391
Post	3.094	2.656	2.922	3.094	3.260	3.313	2.406
Gain	0.250	0.250	0.149	0.031	0.312	(−)0.031	0.136

was viewed from each aspect of SHOM (see **Table 5**). Six aspects of SHOM increased in the mean score and one aspect (OB) decreased. The OM aspect has the highest increased (0.312) while the lowest was for the RA aspect (0.031). The mean increase in other aspects varied from 0.25 to 0.136.

The Differences in Students' Chemical Literacy Before and After the Implementation of the Inquiry Learning Using SSI Context

Based on **Table 6**, we can conclude that there was a significant difference in students' chemical literacy before and after the implementation of the POEEd strategy using the SSI context. Students had better chemical literacy at the end of learning. The result of the effect size calculation shows the d value of 1.85 with an effect of 0.448 (Cohen, 1988). This showed that inquiry learning with the SSI context has a small-moderate effect on students' chemical literacy in the experimental class. Then, **Table 7** shows that the students' argumentation toward acid rain as an SSI had the highest score compared to other SSIs (mean value 1.687 from a maximum score of 2). Meanwhile, two SSIs, namely, consumption of ulcer drugs for fasting people and the use of borax for food, had almost the same mean score. The use of glass cleaner as SSI obtained the lowest mean score.

Table 8 shows another result of data analysis for students' opinions about SSIs, i.e., types/coding of opinion. For the first SSI (acid rain), most students (71.8%) agreed with the factory construction policy both in big cities and in areas with certain

TABLE 6 | Paired *t*-test for chemical literacy in the inquiry learning using the SSI context.

	N	Mean	SD	df	*t*-value	*P**	Conclusion (*)
Pre-Post	32	−24.062	4.517	31	−32.739	0.000	Significantly Different

(*) Computed using alpha: 0.05.

TABLE 7 | The score of students' argumentation toward SSI in the chemical literacy test in the experimental class.

SSI	N	Acid rain	Ulcer medicine	Borax	Glass cleaner
Mean	32	1.687	1.281	1.312	1.218

requirements. Most of the students (75%) stated that a person who has chronic gastric pain and using ulcer drugs should keep fasting during Ramadan if they get permission from a doctor. Then, all students showed their rejection attitudes toward the issue of the sale of borax, which is sold freely and without a license and is abused as a food additive. Later, concerning the use of glass cleaners, no one thought that it would affect human health. It seems that all students do not aware of the controversy over the use of glass cleaner.

DISCUSSION

The Effects of Inquiry Learning Using SSI Context Toward Students' SHOM and Chemical Literacy

The implementation of the POEEd-SSI strategy indicated a significant effect on students' SHOM and chemical literacy. The characteristic of inquiry learning that emphasized student activeness in constructing their knowledge urges students to practice their scientific habits in thinking by asking scientific questions and finding solutions to problems. Meanwhile, the use of SSI promotes students' sensitivity to scientific problems in their social life. This process develops students' chemical literacy ability. An in-depth analysis of the effectiveness of learning can be viewed from the characteristics of the selected inquiry strategy, namely POEEd. The POEEd-SSI strategy was developed in acid-based learning to strengthen the habituation aspects and the development of student reasoning.

It is not easy for students to relate the SSI problems specifically with the concept of chemistry, but they can have discussions with friends in a small group. Then, students predicted the link between the acid-base concept and the SSI presented, namely, ulcer drugs, borax circulation, cyanide in cassava, and the habit of chewing betel leaf. This process develops students' curiosity and makes students' minds more open to scientific problems in their social life. For instance, students know that the misuse of borax as a preservative, which contains certain chemicals, may make health worse. However, students have not been fully able to relate this with the chemistry concept. The POEEd-SSI strategy bridges teachers to introduce daily life phenomena with chemistry concepts. In other words, students' SHOM start to be trained at this moment. This strategy will overcome the lack of relevance of chemistry, which affects low student learning interest (e.g., Acar and Yaman, 2011; Ültay and Çalik, 2012; Zowada et al., 2018).

Moreover, scientific inquiry extends not only to the development of processing skills but also to promoting students' scientific reasoning and critical thinking to develop scientific knowledge (Lederman et al., 2014). Students evolve their critical thinking, accuracy, and decision-making to obtain scientific answers to predictions that have previously been made. The activity of answering and asking questions assists in the development of students' critical thinking positively (Duran and Dökme, 2016). Moreover, critical thinking ability supports the development of students' chemical literacy by linking to claims and the evidence of problems (Henderson et al., 2015). Then, the third step (explanation) facilitates students' use of their rational reasoning ability to make arguments toward the made conclusions. Students develop their mind related to objectivity, rationality, and suspension of belief (as SHOM aspects) during the discussion. Students use their thinking to consider the best solution in overcoming the problems that be founded in the previous stage. Then, students make decisions objectively based on supporting facts and theories. Discussions with the support of independently collected evidence improve the quality of students' arguments (Karışan et al., 2018. On the other hand, learning in groups provides opportunities for students to exchange ideas, collaborate, and achieve conceptual understanding jointly. Group collaboration also trains students to interact with others. It will support the development of their transferable skills for future life.

Students explore the problems related to ulcer drugs, borax circulation, cyanide in cassava, and the habit of chewing betel leaf. This is all to answer the questions "what impacts do these phenomena have on individual's lives, society, and the environment?", "Is it true that the phenomena are controversial?," and "who is the group that opposes the existence of this phenomena?" These questions help students to see aspects or dimensions of SSIs. The discussion indicated that most students still see SSIs from a dominant and familiar dimension in society. For example, for the use of ulcer drugs, students focused on the health dimension, not being able to see other dimensions. This was different when the same SSI was later used as a topic in chemical literacy tests. Students can sight another dimension of ulcer medicine when it is related to the obligation to fast in Ramadan for the Muslim community. Other SSIs are also as seen as a dimension of health as the main dimension.

However, a deeper analysis related to SSIs supports students in the development of their reasoning. The use of SSIs in inquiry learning encourages students' decision-making skills (Bayram-Jacobs et al., 2019). Moreover, the existence of SSIs in this step contributed to students' understanding of relevant aspects of chemistry education (e.g., Gilbert, 2006; Stuckey et al., 2013), which also encourages their chemical literacy (Cigdemoglu and Geban, 2015; Wiyarsi et al., 2020). The breadth of students "insights and experiences affects students" thoughts on SSI more comprehensively. These aspects still need to be initiated better also as often as possible in learning chemistry to

TABLE 8 | Percentages of coding for students' argumentation toward SSI in chemical literacy test.

SSI and argumentation tasks	Responses/ Frequencies (percentages)		
Acid rain Students make argument toward the government's efforts to improve society's economy by building industrial factories that contribute to smoke pollution (e.g., acid rain) in big cities and the certain region	Fully disagree 4 (12.50%)	Agree with the certain requisite 23 (71.87%)	Neutral/no problem 5 (15.62)
Ulcer medicine The student makes an argument regarding a person who has chronic gastric pain and using ulcer drugs since they must do the Ramadan fasting	No need for fasting 7 (21.87)	Fasting with certain requisite 24 (75.00%)	Keep to fasting though have to consume ulcer medicine every day 1 (3.12%)
Borax in food Students make an argument regarding the sale of borax, which is sold freely and without a license.	Showing the rejection attitudes 32 (100%)		
Glass cleaner Students make an argument about the use of glass cleaner as a cleaner for the bathroom floor, including their safety and its effect	Can be used, and there is nothing to worry about concerning the hazards and their impacts 20 (62.50%)		Cannot be used 12 (37.50%)

encourage students to become responsible citizens. Furthermore, incorporating a science inquiry practice into an SSI debate has the potential to improve students' disciplinary engagement and the quality of their argumentative practice (Nam and Chen, 2017).

The Effects Before and After the Implementation of Inquiry Learning Using the SSI Context Toward Students' SHOM

The result shows that the use of the POEEd-SSI strategy promotes students' SHOM. Fostering SHOM is required for the next generation facing economic, social, and environmental challenges (Knight, 2011). Through the POEEd-SSI strategy, students improve in terms of mistrust of arguments with authority and skepticism, as SHOM aspects, especially when it comes to how they act when facing controversial issues. The inquiry learning enables them to be skeptical because they are actively constructing their new knowledge by themselves through discussion in small groups. Thus, they treat any information given by others skeptically even if given by the teacher that holds positions of authority. The inquiry learning facilitates in the students an opportunity to realize that all new ideas are potentially open to critical appraisal. Since they open to any critical, it brings the students to become receptive to new ideas. Thus, the open-mindedness value signifies the highest improvement. Students have been familiar with inquiry-based learning but they not familiar yet with the presence of SSIs. Meanwhile, SSIs significantly contribute to students' SHOM (Çalik and Karataş, 2019). Therefore, the use of inquiry learning that combines with SSIs strongly contributes to the development of students' SHOM (Grooms et al., 2014).

Furthermore, while students work in their group, they could not conclude too quickly. They should make sure that the evidence is sufficient to construct a conclusion. That is, the SSI is integrated and has several dimensions related to an ill-structured and controversial problem. Thus, the evidence achieved by the students was varied. The SSI allows the students to frame an argument in a personally meaningful way (Balgopal et al., 2016). Therefore, there is not always sufficient evidence to make a decision, and students should therefore not rush in too quickly to support a particular idea or theory (Gauld, 1982, 2005). This fact that brings students to suspend their belief and thus after applying inquiry learning with SSIs, their SOB is improving.

Phrased differently, the SSIs enable the students to explore the issues around them, and they thus realize that chemistry is closed to their everyday life (Ültay and Çalik, 2012; Çalik et al., 2014). The idea that chemistry is a part of everyday life that made students' curiosity is sharpening. The students realized that chemistry is beneficial for their lives; thus, it could attract students' desire to learn chemistry. Students were curious about the issues to have been shown by the teacher. They have had a chance to use their scientific knowledge as responsible citizens (Çalik and Cobern, 2017). This suggests that increasing curiosity about SSI and improving their SHOM awaken in them a desire to learn systematically (Hodson, 2003; Çalik et al., 2014). Therefore, an improvement in students' curiosity was identified in this study.

Socio-scientific issues not only enhance students' curiosity but also stimulate students' intellectual and social growth, and they thus engage in reasoning by considering any evidence and argumentation (Sadler, 2004; Çalik et al., 2014). The POEEd-SSI strategy demands a good reason and logical argument in solving problems. Thus, there is no doubt that skills of scientific argument should be adopted by the students during the discussion activity. Decision-making in the context of SSI includes rationales in making their arguments (Grooms et al., 2014). In decision-making about SSIs, students should apply good reasoning and use appropriate evidence to form a logical idea. Moreover, the use of rationality in an argument implies that the students realized that any other reason may appear in the same argument. Through the use of rationality, the students further described why the reasons they chose are valid and acceptable in the context of the task. Hence, students' rationality is enhancing even though it still needs to be improved. Phrased differently, apart from rationality, objectivity has an essential role for students in decision making. They need to be objective when supporting a claim. However, contrary to the above, the results of this research signified a slight decrease in students' objectivity after learning using the SSI-inquiry strategy. It proves that students need to be more familiar with the use of SSIs in chemistry learning so that people might improve their objectivity when making a decision. The lowering of students' objectivity may come from Indonesian people's habits that easily to be provoked them. This means that increasing students' SHOM requires a longer intervention period with greater emphasis on making such decisions (Walker and Zeidler, 2007). The support of inquiry learning using an SSI context in students' argumentation toward SSI in particular is explored through the chemical literacy test.

Overall, students' chemical literacy improved after the implementation of the POEEd-SSI strategy. Students have a good mastery of acid-base theory and acid-base indicators as well as acid-base calculations as one aspect of chemical literacy. Particularly, this section focuses on discussing students' arguments about the four SSIs related to the concept of acid-base as another indicator of chemical literacy. The results of the analysis showed that the quality of the students' arguments was the best against acid rain, and this was followed by arguments against the use of borax and ulcer drugs. The weakest argument was shown for glass cleaner. This fact may be related to how often students hear issues either directly, through everyday stories, or highlights from the mass media. In particular, it depends on the social conditions in which students live, and, in general, it is related to national issues. In the Indonesian context, acid rain and the use of borax are very familiar to the public, and the mass media also discusses these subjects frequently. Students were more concerned and sensitive about the issues around their life (e.g., Karahan et al., 2017; Wiyarsi and Çalik, 2019).

The first SSI that was used as a topic in A-BCLT was acid rain. The questions raised related to the possibility of developing a large and sustainable industry/factory. Most of the students agreed with the requisite toward large-scale industrial or factory development due to their impact on environmental damage and the decline of public health. Industrial/factory development can be carried out as long as the government makes strict regulations in terms of limiting the number, places that are far from residential areas, the balance of available green land, and the application of appropriate waste treatment technology. In this case, students could see a problem from various angles, industry players, authorities, consumers, and society in general. This is a good point for developing student awareness of various problems in society.

Another group with a smaller number of students stated that they did not have a problem with building factories or industries in large part in both cities and villages. The reason is for the country's progress and existence in global competition. Students put their thinking more emphasis on aspects of the benefits of the development of science and technology to facilitate human life and see from the point of view of industrial players. Nonetheless, students argue that the industry has to treat waste before it is discharged into the environment (including the use of air filters in chimneys) and to increase the use of biofuel.

Meanwhile, only a small number of students expressly disagree with this case. The main reason is that the construction of factories has more negative impacts, such as reducing soil fertility, reducing green land, and causing air pollution and damage to the environment due to acid rain. Acid rain damages buildings cause chlorosis of plants and indirectly affects human health. Even though students realize that building a factory will create jobs, they prefer other alternatives. The government is better off encouraging the use of the local potential for strengthening the national economy rather than building industries and factories. This potential includes the development of agriculture, animal husbandry, and tourism while still paying attention to environmental safety aspects.

The response to the SSI of using ulcer drugs when Muslims are fasting is divided into three opinions. First, most students respond that sufferers are better off not fasting for those who are at high risk and may still fast for certain people as long as it is based on a doctor's recommendation and follows medical procedures. The second response by a small proportion of students stated that ulcer sufferers do not need to fast because religion allows people to replace fasting with other obligations if they are unable. Interestingly, there was one student who stated that ulcer sufferers had to keep fasting because it was an obligation: God will help anyone who follows his orders. This fact shows that belief trumps students' rationality about a scientific issue. This situation is influenced by many things such as parenting styles, local culture, and the educational environment, and the origin of the student.

The third SSI is related to the use of borax as a food preservative. Students give the same response to this phenomenon, namely refusing because it threatens public health, especially for children. Economic reasons do not necessarily justify violations. This matter is the responsibility of the government. Students' attitudes toward this issue include the need for government assertiveness in enforcing regulations on borax sales, education for the community as well as providing economic solutions, and strict penalties for lawbreakers. On the other hand, each person also must increase self-awareness in maintaining health by being more careful in choosing food products for consumption. If the community already has good awareness, there is no opportunity for people to use borax.

The lowest quality argument was achieved for SSI's use of glass cleaners. Students elaborated on a good scientific rationale for the possibility of glass cleaners also being used as floor cleaners. However, the response of most students implies that they do not consider the use of cleansers to be SSI. Some of the other students do not even comment at all. Students were not yet fully aware of the pros and cons of using glass cleaners in their daily life and how this can harm human health in the long term. That is, enhancement of meta-level awareness of the use of evidence in arguing of SSI is affected by the topic and timing (Iordanou and Constantinou, 2014). This shows that the integration of various SSIs needs to be done in chemistry and science learning to increase student awareness. Moreover, the existence of SSI will develop the quality and quantity of student arguments (Çapkinoglu and Yilmaz, 2018) and students' decision making (Evagorou et al., 2012), which supports the realization of scientific literacy as a requirement for becoming a responsible citizen.

CONCLUSION AND IMPLICATION

The use of SSI as context during inquiry learning with the POEEd strategy facilitates student involvement and activities in identifying, relating/linking, and analyzing scientific information on controversial social issues with scientific concepts (chemistry). Students' habits of scientific thinking develop in this study, although not as better as increasing chemical literacy. The important implication is that teachers should bring up SSI problems more frequently in chemistry learning and involve students in making decisions about these problems based on their scientific knowledge. Furthermore, a chemistry teacher self-development programs are needed in analyzing SSI related to chemistry and science concepts in general and then developing appropriate learning designs.

This study has limitations, such as the relatively small number of samples, the observation step not always being carried out with experimental activities in the laboratory, and how the SSI that is used on the SHOM scale is not fully familiar to students. Future studies may involve local SSIs that are very closed to students' life, such as an SSI that was discussed during the implementation of the POEEd strategy.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

The study is presented as a manuscript in any academic activities of AW. AP and AN have contributed in reducing any missing points and improving the English language. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.660495/full#supplementary-material

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