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Empirical Foundations for Developing New Learning Models to Improve Chemical Literacy, Scientific Habits of Mind, and Science Process Skills of Chemistry Education Students

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Abstract: The development of a new learning model to increase chemical literacy skills, scientific habits of mind (SHOM), and science process skills (SPS) of chemistry education students is needed to prepare competent chemistry teacher candidates in the future. Theoretical studies have discussed the low chemistry literacy, SHOM, and SPS of students. This research aims to prove the theoretical study data by looking directly at the conditions of chemical literacy, SHOM, and SPS of chemistry education students. The research took place in four stages: measuring and comparing chemical literacy; measuring SHOM; observing SPS during learning activities in the laboratory; and conducting needs analysis for lecturers. The scores obtained from measuring chemical literacy are very worrying. However, there are significant differences in chemical literacy as the years of study increase. Student SHOM is also still in the medium category and needs to be improved. Student SPS is also still relatively low. Furthermore, the lecturers suggested developing a learning model that could develop these three abilities. The model developed must be suitable for adult learning and be able to develop student abilities.

Keywords: Chemical literacy; Chemistry education; Science process skills; Scientific habits of mind

Introduction

The era of disruption has become a reality that must be faced by the world community, including Indonesia (Pratama & Rohaeti, 2023). The impact of this era causes Indonesia's young generation to be qualified and able to compete at the global level to meet the demands of success at work and for their future (Asrizal et al., 2018; Ball et al., 2016; Novitra, 2021). However, the formation of a quality generation still faces many obstacles such as mental health disorders, low enthusiasm for competition, and lack of literacy and problem-solving skills (Arciniega et al., 2023; Edwards et al., 2023; Perry et al., 2020).

One way to produce a generation that is qualified and able to compete is by improving literacy skills to obtain life skills. However, the results of the Indonesian Program for International Student Assessment (PISA) are still less than satisfactory. The scores obtained for the reading field in 2009, 2012, 2015, 2018, and 2022 respectively were 402, 396, 397, 371, and 359, while in the science field, they were 383, 382, 386, 396, and 366 (OECD, 2023). Based on these results, it can be said that the literacy and science levels of junior high school students in Indonesia are still relatively low (Asikin & Yulita, 2019; Siami et al., 2023).

Another international study involving older people, the Program for International Assessment of Adult Competencies (PIAAC) assessment in 2016, also showed that adults are still frail in terms of literacy and problem-solving (Perry et al., 2020). The results from PIAAC show that 70% of respondents in Indonesia have

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literacy skills at level 1 and below. This can mean that adults in Indonesia can only read short texts on topics that are familiar to them and can only capture one message or information from the text (Keslair & Paccagnella, 2020).

Current education can be modified to build a deep and multidimensional model of scientific literacy (Cigdemoglu & Geban, 2015). Modifications to build a literacy model need to be implemented in education in Indonesia. One part of literacy is science literacy. Science literacy can be defined as science skills that require students to be able to identify a phenomenon, explain the phenomenon scientifically, and draw conclusions based on analysis. Then students are also required to understand science's characteristics, be aware of the role of science in the environment, social and cultural aspects, and develop a caring attitude towards science-related issues (OECD, 2015).

Science literacy can be further narrowed down to chemical literacy which discusses chemical knowledge and skills to understand the role of chemistry. The three components of chemical literacy are basic chemical concepts, the role of chemistry in academic life and beyond, and chemistry in a societal context (Kohen et al., 2020). Students need to gain chemical literacy because it can equip them to make decisions (Sevian et al., 2018), make students more critical, and creative, and help them in solving many everyday problems or natural phenomena based on their knowledge (Wiyarsi et al., 2020), and integrating chemistry to decide a case involving ethics (Pratama et al., 2023). Therefore, if students have competence in understanding the framework and use of chemical knowledge to solve daily life problems or natural phenomena, then these students have good chemical literacy skills (Shwartz et al., 2006). Based on the urgency regarding the importance of chemical literacy, students need to obtain chemical literacy because it can equip them to make decisions (Sevian et al., 2018).

Behind the importance of chemical literacy, many studies state that students' chemical literacy abilities are still low (Stasevic et al., 2023). Other research states that students are not used to analyzing complex information or reasoning (Muntholib et al., 2020). Therefore, chemistry education students must obtain chemical literacy in learning. This ability will enable chemistry education students to become professional chemistry teachers in the future.

Apart from the development of educational goals, other challenges from the era of disruption in the 21st century include the rapid development of science and technology in various areas of life. The development of science and technology cannot be separated from the hard work of scientists who have habits of mind, one of which is scientific habits of mind (SHOM). SHOM is one of the skills that a person must have to adapt (Griffin et al., 2012). Marzano (1994) suggests that SHOM is a dimension of long-term learning outcomes. Affirmation of this opinion was recorded in research conducted by Hayat et al. (2019) which showed that SHOM gave birth to many scientific attitudes and developed values within it. SHOM is also useful for characterizing how scientists think (Çalik & Coll, 2012; Gauld, 2005).

However, in reality, not many students have SHOM like scientists (Pratama & Rohaeti, 2024). When lecturers present chemistry material in class, many students are indifferent to the lecturer's explanation. As a result, many students are less interested in participating in education, feel bored, and are not motivated to improve their learning achievements (Cholifah et al., 2016). This is exacerbated by the perception of many students who think that basic chemistry is a difficult subject because it is abstract and complex (Priliyanti et al., 2021). Other students have difficulty learning chemistry because they cannot connect chemical concepts and think that chemistry is irrelevant to everyday life (Zakiyah et al., 2018).

Another skill that students can use to face the disruption era of the 21st century is science process skills. Science process skills are considered a prerequisite for students to understand the nature of science and solve scientific problems (Tosun, 2019; Zimmerman, 2007). Several previous studies confirm the existence of a correlation between science process skills and formal reasoning abilities (Padilla et al., 1983; Shaibu & Mari, 2003), learning achievement (Delen & Kesercioğlu, 2012; Feyzioğlu, 2009; Hernawati et al., 2018; Osman & Vebrianto, 2013), self-efficacy, creativity (Özgelen, 2012), and scientific attitude (Zeidan & Jayosi, 2015).

Through the application of science process skills, students are involved in the process of developing curiosity and growing intellectual skills. If these conditions are achieved, it will be easier for them to analyze and evaluate problems, as well as discover new knowledge using scientific skills. However, there are findings of a decrease in science process skills as the years of study increase (Çalık et al., 2015). The same results were stated by Cigdemoglu et al. (2015) who said that there was a decrease in student attitudes after receiving instruction, although it was not significant.

Based on this description, chemistry learning at the university level must provide learning that can improve chemical literacy skills, get used to scientific thinking, and train the scientific process skills of students who will become prospective chemistry teachers in the future. Chemical literacy skills are included in the cognitive aspect, scientific thinking habits are included in the affective aspect, and scientific process skills are included in the psychomotor aspect. The development of these three aspects aims to implement the Undergraduate

Chemistry Education Study Program following the Indonesian National Qualifications Framework (Kerangka Kualifikasi Nasional Indonesia (KKNI)) at level 6. Graduates are expected to have the ability to master concepts, formulate procedural problem-solving, make decisions, apply skills, utilize science and technology in solving problems, adapt to the situation faced, and be responsible for the achievement of work results.

Several initiatives have been implemented to enhance students' capabilities, such as adjusting educational resources, developing learning methodologies, and refining instructional models. In this scenario, adaptations to the learning model are necessary to yield a solution conducive to adult learning. This is imperative as the focus of developing this learning model is geared towards undergraduate students aged 17 to 22. This learning model is known as the tertiary learning model.

An example of a tertiary learning model specifically developed for chemistry education students is Research-Oriented Collaborative Inquiry Learning (REORCILEA). However, this model is aimed at developing students' critical thinking skills, SPS, and scientific attitudes simultaneously and individually. Previous research also proves that REORCILEA has a positive impact on these three abilities (Irwanto, 2022; Irwanto, 2023; Rohaeti et al., 2020). Currently, no tertiary learning model is available that can develop chemical literacy, SHOM, and SPS skills simultaneously and individually.

Therefore, the development of a tertiary learning model to develop students' chemical literacy, SHOM, and SPS skills must be created immediately. Before conducting research, the author has conducted a literature review and empirical study. Empirical studies related to the three abilities that chemistry students must have are summarized in this research, thereby supporting the literature study.

Method

The research method is divided into four parts. The first part is used to measure chemical literacy abilities. The second part is used to see students' responses to the SHOM they have. The third part is used to observe science process skills. The fourth part supports the three parts by collecting opinions from chemistry education lecturers.

Chemical Literacy

To measure chemical literacy, instruments are usually used in the form of chemical literacy questions. Many studies have used chemical literacy questions (Sadhu et al., 2019; Wiyarsi et al., 2021; Wiyarsi, Pratomo, et al., 2020). There is also evidence of measuring chemical literacy using questionnaires (Pratama & Rohaeti, 2024). However, the questionnaire only measures the chemical literacy profile and not the students' specific chemical literacy abilities. Other instruments can be recommended to measure chemical literacy abilities, but for research results to be accurate, the use of chemical literacy questions is still a solution.

The survey method is used to measure students' initial chemical literacy abilities. To obtain a credible data source, research respondents were a crucial requirement. The respondents must be representative of the population to ensure comprehensive representation (Creswell, 2012). The study population comprised 210 students, and the minimum requirement of 20% of the population must be fulfilled as respondents (Gay et al., 2012). A total of 113 students from three different cohorts participated in this measurement.

The instrument used was chemical literacy questions on basic chemistry and physical chemistry topics. Previously, the instrument had passed the face validation stage by asking for opinions from expert judgment using the Delphi technique and empirical validation by being tested on other chemistry education students. The number of literacy questions developed was 10 questions and students were allowed for 1 hour to work on them. The data obtained from student answers is then given a score and analyzed. The first analysis is to measure the average score of each class. The second analysis is to measure the differences between the three groups using ANOVA.

Scientific Habits of Mind (SHOM)

To measure SHOM, the instrument commonly used is a scale (Wiyarsi et al., 2023; Wiyarsi & Çalik, 2019). Another instrument that can be used is the SHOM instrument inserted in a strategy game that gives players various strategy choices. SHOM can be seen from the combination of the players' answers (Steinkuehler & Duncan, 2008). For practical reasons, the author uses the SHOM scale instrument.

Like chemical literacy, a survey was carried out to see the SHOM of chemistry education students. A total of 76 students out of a total of 210 students filled out the SHOM scale voluntarily. This shows that the minimum requirement of twenty percent of the sample representing the population has been met.

The SHOM measurement in this study was adapted to the SHOM scale that had been developed by previous researchers (Pratama, 2023). The SHOM scale tested consists of 25 statement items with 5 alternative answer items. The alternative answers are Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). Each statement item has its value. After that, the collected data is processed by ideal criteria assessment into qualitative data. The result of converting this data is categorical data including very low, low, fair, good, and excellent. In this way, the SHOM of a group of chemistry education students can be determined.

Science Process Skills (SPS)

SPS measurements were conducted by observing the practical activities of Chemistry Education students in the laboratory. The physical chemistry laboratory and inorganic chemistry laboratory situated at a state university in Yogyakarta Province have been chosen for the study. To make the research effective, the researcher was assisted by eight practicum assistants in observing students' SPS. Observations were carried out continuously for one semester. Each practicum assistant is provided with an SPS observation sheet. The SPS observation sheet developed produced qualitative data. Qualitative data in the form of findings from incidents during practicum are then processed by researchers.

Analysis of Learning Model Development Needs

Needs analysis (also known as needs assessment) has a vital role in the process of designing and carrying out any learning product including learning models (Songhori, 2008). In this study, a needs analysis was undertaken to evaluate the actual circumstances of students from the lecturers' perspective. The outcomes of this needs analysis have the potential to either substantiate or challenge prior research findings.

A needs analysis questionnaire has been developed to assist with data collection. This questionnaire consists of four aspects: chemical literacy, SHOM, SPS, and the urgency of developing a learning model. The parts of the needs analysis questionnaire are shown in Table 1. All questionnaire items are open-ended so lecturers can freely express their views on implementing education in the classroom.

Table 1. Parts of a Needs Analysis Questionnaire

Aspect	Indicator	Number
Chemical Literacy	The importance of chemical literacy for chemistry education students	1,2
	The reality of chemistry education students' chemical literacy	3
	Obstacles in teaching chemical literacy to chemistry education students	4,5
SHOM	The importance of SHOM for chemistry education students	6,7
	The reality of chemistry education students' SHOM	8
	Obstacles in teaching SHOM to chemistry education students	9,10
SPS	The importance of SPS for chemistry education students	11,12
	The reality of chemistry education students' SPS	13
	Obstacles in teaching SHOM to chemistry education students	14,15
The urgency of developing a learning	Suggestions for developing learning models that can influence chemical literacy, SHOM, and SPS of chemistry education students	16, 17, 18, 19, 20

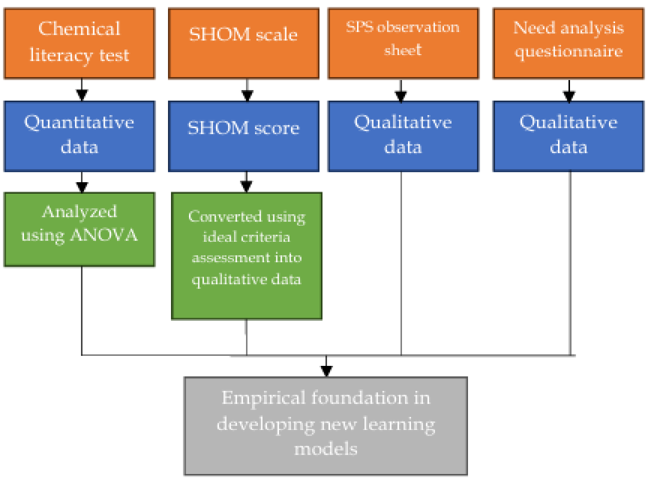

Figure 1. Research method framework

If all parts are summarized into a chart, then the material can be seen in Figure 1. All parts will become an empirical foundation for developing new learning models.

Result and Discussion

Chemical Literacy

The chemical literacy test given to 113 chemistry education students produced unsatisfactory scores. Students were divided into three groups based on educational level. The results of the literacy test are shown in Table 2.

Table 2. The Result of the Chemical Literacy Assessment

Category	Amount	Mean
Freshman	46	11.63
Sophomores	34	31.03
Junior Sophister	33	39.55

Based on Table 2, it can be seen that there is an increase in chemical literacy skills along with the year of study. This increase in chemical literacy is due to the increasing understanding of chemical concepts as students' years of study increase (Cigdemoglu & Geban, 2015). However, the average of these three groups is still low because the maximum score that can be obtained is 100. Next, to find out whether there are significant differences between the three groups. Normality and homogeneity tests were carried out to determine the type of data test used.

Table 3. The Result of the Normality Test

Category	Sig.
Freshman	0.013
Sophomores	0.002
Junior Sophister	0.103

Table 4. The Result of the Homogeneity Test

Test	df	Sig.
Homogeneity	2	0.000

Normality results indicate that the data obtained is not normally distributed, while homogeneity results indicate that the data is homogeneous. Therefore, non-parametric tests were chosen to continue testing to see significant differences. The non-parametric test used is the Kruskal-Wallis test. The results of the Kruskal-Wallis test are the Asymp. Sig. which is worth 0,000. Based on these results, it can be concluded that there are significant differences between Freshman, Sophomores, and Junior Sophister.

This significant difference can be interpreted as an increase in students' chemical literacy abilities. However, the scores from each group are still far from good. Students are not yet able to connect chemical concepts acquired in class with the literacy discourse presented. If they become chemistry teachers, they might get questions regarding the relationship between chemical concepts and everyday life. This of course will make it difficult for the student.

SHOM

The SHOM questionnaire was sent to 76 chemistry education students via Google Forms. The results obtained from the Google Form were quite surprising. The profile percentage of students' scientific habits of mind is 66.89% and is included in the fair category. Upon examination, numerous applications of chemical concepts in daily life become evident. Therefore, improvement efforts are needed so students have the SHOM in learning chemistry.

The lowest result from this research was in the aspect of "not easily believing authority arguments". Students tend to immediately believe statements made by institutions, especially government institutions, without finding out more about the statement. In fact, without realizing it, sometimes institutions can also make wrong statements. Through SHOM, students are expected to be able to filter and re-examine the information obtained so that they can differentiate between true news and false news.

SPS

Based on the results of observations, learning activities in the laboratory still revolve around following the recipe book and writing experimental reports. Students tend not to want to know further reasons about the activities they do in the laboratory. Some students also tend to be passive, only doing a little work and occasionally playing with gadgets in the middle of learning. The results of observations regarding practicum reports written by students also still give the impression of formality. Not many students have discussed their findings in-depth and comprehensively. The literature used also still focuses on practical manuals and does not use many scientific articles. Even if someone uses a scientific article as a reference in writing a practical report, the scientific article is not the latest scientific article.

When students do experiments, no one asks about the reasons and benefits that would be obtained from this practicum. Some students also seemed unable to operate simple practical tools such as adjusting the buret tap, taking solutions with a ball pipette, and setting up a simple polarimeter. When experiencing obstacles such as the unavailability of a chemical, students cannot choose chemicals that have similar properties to chemicals that are not available in the laboratory. This shows that most students have not been able to apply the knowledge gained from theory classes in practical classes so it can be said that the science process skills of chemistry education undergraduate students are still relatively lacking.

Results of the Needs Analysis Questionnaire

Eight chemistry education lecturers participated in filling out the needs analysis questionnaire. All lecturers said that chemistry, SHOM, and SPS literacy were very important for students. These three abilities can prepare students to become competent chemistry teachers. However, the results of these three capabilities are still lacking and need to be improved. Based on the results of the needs analysis questionnaire, there are many obstacles in training these three abilities, such as the habit of students who like to understand concepts instantly in solving problems, the ability to understand reading and chemistry concepts is still low, the lack of practicums based on daily life problems and projects, lack of discussion time due to busy student activities, and evaluations that do not explore chemical literacy, SHOM, and SPS of chemical education students.

All lecturers emphasized the necessity for educational adjustments to enhance students' chemical literacy, SHOM, and SPS. Lecturers have hitherto focused on modifying learning media, adjusting strategies, and adapting learning materials. There are no lecturers who have taken the initiative to develop new learning models. However, the lecturers agree that the development of new learning models must be carried out. Learning models can be developed by modifying existing learning models, and then adding sections according to needs. To enhance chemical literacy, as well as SHOM and SPS, the instructional model developed should incorporate learning activities geared towards refining high-level cognitive skills.

Conclusion

The development of science and technology in the disruption era of the 21st century is a challenge for educational institutions, especially universities, to prepare competent chemistry teacher candidates. However, this study's findings reveal that chemistry education students' chemical literacy, SHOM, and SPS are still relatively low. This is reinforced by the arguments of chemistry education lecturers who say that it is necessary to modify the learning model. The findings from this research can be used as an empirical study related to the development of a tertiary-level learning model that specifically develops chemistry education students' chemical literacy, SHOM, and SPS abilities.

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F.I.P.; methodology, format analysis, investigation, data curation, and paper preparation E.R.; methodology, validation, and data curation E.W.L.; paper review, research permit, and editing. All authors have to read and agree to the published version of the manuscript.

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The authors declare no conflict of interest.

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