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Fostering students' scientific literacy and communication through the development of collaborative-guided inquiry handbook of green chemistry experiments

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Fostering students' scientific literacy and communication through the development of collaborative-guided inquiry handbook of green chemistry experiments

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Abstract. Industrial revolution 4.0 requires a person to be literate, as well as science students who have to achieve science literacy through experimental activity. The aim of this research is to develop a collaborative-guided inquiry handbook based on green chemistry vision for general chemistry experiment to promote the students' scientific literacy and communication skills. Preliminary observation found that in general, students faced difficulty to relate chemistry concepts to the experiment they had done through expository model. As a result, they were unable to modify procedures, variables, and chemicals needed to meet green chemistry principles. Developing a collaborative-guided inquiry handbook based on green chemistry vision is expected to cope with the problems as mentioned. This research implemented Borg and Gall's research and development method excluded dissemination phase. Validation from two experts were very valid for the handbook (92,85%), communication skill assessment (94,32%), reflective journal (93,75), and questionnaire (96,88%). The development was also effective because questionnaire performed that more than half of students attained science literacy standard (69,23%) and the vast majority of students (93,7%) agreed that guided experiment laboratory model based on green chemistry vision is useful and they want to apply it for next laboratory activities.

1. Introduction

The industrial revolution 4.0 influences several aspects of society, one of which is education. Higher education curriculum should adjust to the demands of the industrial revolution 4.0 [1-3]. Universities must prepare their graduates to be ready to face the challenges of the industrial revolution 4.0. This is what underlies tertiary institutions to improve scientific literacy and new literacy, namely data, technology and resource literacy in students. Likewise, at the elementary and secondary education levels, new literacy is also mandatory for students. To develop the scientific literacy of students, teachers must also have the ability of scientific literacy first. Thus Science Education students as Integrated Science teacher candidates must of course, be required to have high scientific literacy skills and new literacy in order to be ready to become teachers who are responsible to enhance science literacy skills of junior high school students.

General Chemistry Experiment course in 2018 had been held in the form of cookbook lab model, that the students only followed the procedures in the practicum manual. This form of practicum had many weaknesses among others: 1) students were less motivated to be actively involved cognitively, 2) students were lack on initiative, 3) students were limited to explore, and 4) students could do experiments but they did not understand the underlying concepts [4-6].

Observation which was conducted during students' lab report presentation showed that most of the Integrated Science students still had difficulty connecting the concepts with their application in the practicum activities they were doing. Students were also less skilled in conducting scientific communication. For example, PowerPoint slides were still filled with sentence lines, data analysis was sometimes done wrong, and students generally still had difficulty distinguishing chemical terms such as normality with molarity, solubility with concentration, and so on. Lecturers had to explain the relationship between concepts and their application in practicum so students could finally understand. These things affect the ability of scientific literacy and scientific communication of Integrated Science students.

Referring to Bybee [7], scientific literacy consists of four conceptions, namely the scientific context, scientific knowledge, scientific competence, and scientific attitude. Students who have high scientific literacy means that they are able to use scientific knowledge and scientific attitudes correctly. Knowledge and scientific attitude will affect scientific competence by identifying scientific issues and phenomena and using scientific evidence to understand the scientific context. The scientific context is a situation in everyday life related to science. If students have not been able to use their scientific competence to understand situations in daily life and have not even been able to link theory and its application to practicum, it can be identified that students' scientific literacy skills were still weak. Meanwhile, recent science curriculum prioritizes not only on comprehension of scientific knowledge and its usefulness but also on the value of learning as transformation tool on learners and society [8-9]. Graph 1 illustrated the relationship among those four concept of scientific literacy.

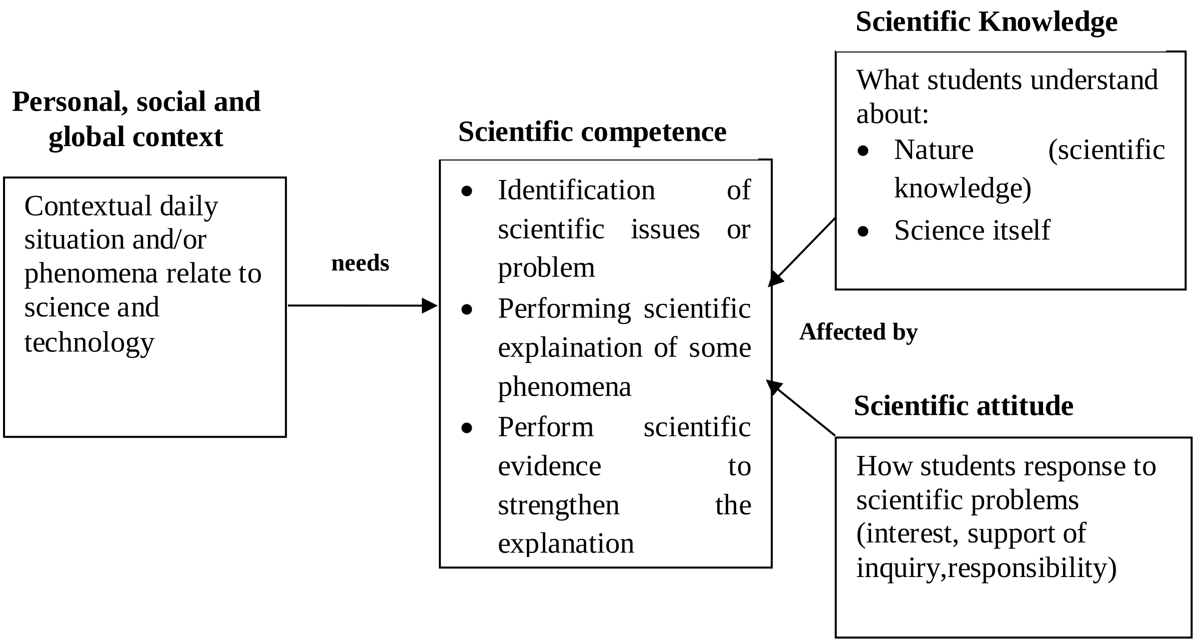

Figure 1. Relationship of scientific knowledge, attitude, and competence contribute to students' personal, social, and global context (scientific literacy)

An important aspect that supports experiment is laboratory capacity. Starting in 2019, the General Chemistry experiment course for Integrated Science students took place in the Integrated Science laboratory. The laboratory is still new established so that the apparatus, chemicals, facilities and infrastructure owned are still limited. In addition, in the old General Chemistry handbook, the chemicals used were several toxic materials, such as hydrogen peroxide, concentrated HCl, chloride salts, sulfate salts, and so on. Practical waste disposal from toxic chemicals must be treated first so that it is not harmful to the environment. Because the Integrated Science lab does not yet have a waste water treatment, the replacement of Basic Chemistry practicum materials with more environmental friendly materials needs to be done. The idea of environmentally friendly chemistry is often known as green chemistry with 12 basic principles of effective, efficient, and environmentally friendly chemistry practicum that support Education for Sustainable Development (ESD).

With regard to those problem, it was considered important to alter the expository model that has been used with model that are in accordance with the capacity of the lab and can encourage initiative, increase scientific literacy and scientific communication skills of prospective Integrated Science teacher candidates. Development of collaborative guided-inquiry based on green chemistry vision to promote scientific literacy was chosen as an alternative solution to tackle the problem.

2. Method

Collaborative guided-inquiry handbook was developed with Borg and Gall's R and D from identifying potentials and problems up to field testing. Prototype of the handbook had been validated by two expert from education and green chemistry expert to assess the handbook. Research subjects were students of Integrated Science semester II academic year 2018/2019 on General Chemistry Experimental Course. In small scale trial, 10 students were given the handbook and conducted one experiment. Other developed instruments were also being utilized to assess students' scientific literacy. Weaknesses found in small field testing and experts' suggestion were utilized to improve the handbook. Improved handbook then was being utilized on large scale trial with 58 first-year undergraduates involved. At the end of class, they filled out a questionnaire to give their response upon the handbook and its implementation.

3. Result and Discussion

3.1. Validity of learning materials

The first step in developing the manual was to carry out an analysis of the old practicum manual to find out which procedures had a green chemistry vision and which procedures need to be modified in accordance with the principles of green chemistry. For example, the experiment of separation of mixtures and physical and chemical changes does not use hazardous chemicals but uses dirty salt, ink markers, and tea. Therefore, the trial procedure would still be used. Further analysis in the manual shows that manual of standard apparatus had not been included even though that was an important aspect so students understand the function and name of the tool.

Next step was developing a handbook. On the first page of the book, the twelve principles of green chemistry from Anastas and Warner [10] were written so that students understand the modified procedure must meet at least one principle. A science literacy assessment matrix tailored to the learning outcomes of graduates from the Science Education Curriculum was also included. The tool introduction page then displays images of some of the most commonly used tools. Then enter the core pages, the first to thirteenth experimental procedure. After the handbook was finished, content and media experts assessed and validated it. Other tools that also be developed and needed validation was assessment sheet of communication skill, reflective journal, and questionnaire. Table 1 performs validation result of them.

Table 1. Validation result from content expert

Learning materials	Score	Criteria
Collaborative guided-inquiry based on green chemistry for general chemistry handbook	92,85 %	Very valid
Communication skill assessment	94,32%	Very valid
Reflective journal	93,75%	Very valid
Questionnaire	96,88%	Very valid

The suggestions from the content validator were: (1) for scientific literacy measurements, please add more questions; (2) for scientific communication instructions, please add the output of guided-inquiry; (3) at the beginning of the activity it is recommended that there be special instructions. Regarding those, some improvements need to be done. There were 3-5 questions added on every experiment topic that must be answered by students after they did experiment. The handbook was also completed with list of assessment of students' performance so it helped students to figure out how to perform well. Special instructions for each experimental topic were written in efficient sentences to make sure that students who read it understand that every single topic has different technique and concept they should comprehend. Revised version that have been improved was then printed out and used for small-scale trials.

Layout of the handbook was also criticized by media experts generated these recommendation: 1) instead of a picture of building, pictures that relate to general chemistry experiment such as pictures of atoms, test tubes, distillation tool sets, and so on would be more appropriate displayed on book cover; 2) name of the writer who was originally written as 'Integrated Science Teaching Team' should be changed to the names of the authors itself; 3) pictures need to be added to the laboratory technique guidelines to make it easier for students to understand the instructions given.

3.2. Small-scale trial

Small-scale trial was conducted to obtain feedback from users, namely Science Education students. The subjects of the small-scale trial were students of the Natural Sciences class B of 2018 totaling 10 students. The trial include testing the use of practical manuals and testing the use of scientific literacy assessment and scientific communication which include: student reflection journals (science content), observation sheets of practical skills in collaborative guided inquiry models with green chemistry vision starting from planning, implementing, making laboratory report (science process and context), student reflection journal and student response questionnaire (science attitude).

The results of the recapitulation of student questionnaire on a small-scale trial showed that in general students can follow the lecture model well, but there are a small number of students who think that instruction neither the handbook provided were easy to understand. Based on these entries, improvements need to be made to the handbook content especially the instructions section. The instructions in the handbook were made more technical and conveyed again with verbal explanation from the lecturer to ensure students understand correctly all the instructions given. In addition, lecturers assisted by assistants need to fully assist students in practicum activities so that mistakes in practicum can be avoided as much as possible. The implementation of these improvements was carried out in large-scale trials.

3.3. Large scale trial

Large-scale trials were conducted to obtain feedback from users with a larger number of 58 students of the 2018 Natural Sciences Education class. Large-scale trials were conducted in the same implementation as the small-scale trial stages with the aim of finding out the effectiveness of the use of the handbook then assess students scientific literacy and scientific communication which includes: student reflection journals (science content), observation sheets of practicum skills in collaborative guided inquiry models with green chemistry vision, starting from planning, implementation, to reporting the results of experiments (science process and context), student reflection journals and student response questionnaires (attitude of science).

The effectiveness of modules used could be measured through questionnaire and the value of positive responsiveness which contain of 14 statements as performed on Table 2. Questionnaire analysis was done by adding up the positive responses of students (answering strongly agree and agree) compared to the number of negative responses (answered less agree and disagree).Almost all students gave positive response toward the use of the handbook (93.7%), while only 6,29 % stated negative ones. For each statement response, statement 3 showed the most negative response from students (23 of 58) but there were more students (35) gave positive feedback. In general, average number of student who gave negative response on every statement was one up to six as illustrated by Figure 2. Therefore, it was noticeable that most of them found fruitful aspects for utilizing the handbook on chemistry experiment.

Table 2. Questionnaire's statement to analyze students' response upon the implementation of collaborative guided inquiry handbook on general chemistry experiment course

No	Statements
1	I understand all the instructions given handbook's guide.
2	All the tasks from the lecturer I try to do optimally.
3	I have no difficulty in doing all the basic Chemistry Practicum assignments.
4	I am optimistic that I will get the maximum score because I have tried my best to do the assignments.
5	Assigning practicum reports from lecturers is very useful in developing written communication skills.
6	Assigning presentation of practicum results from lecturers is very useful in developing verbal communication skills.
7	The preparation of practicum procedures independently made me have a courage to modify procedures or variables
8	The preparation of the practicum procedure independently made me understand concept underlying an experiment
9	The application of collaborative-guided inquiry practicum models is very useful for developing the scientific literacy skills of prospective junior high school science teachers
10	The application of a practicum model with a green chemistry vision is very useful for developing practical skills for junior high school science teachers candidates
11	The application of the practicum model with the vision of green chemistry (environmentally friendly chemistry) made me understand that chemical practicum procedures can use materials that are less / not harmful to the environment and save energy
12	I became wiser and more careful in determining the material I would use for practicum
13	I have tried to minimize practicum waste such as using water, electricity, practicum materials, and tissue to taste
14	In the future, I will use the knowledge and skills I gained from learning experience in the general chemistry experiment course

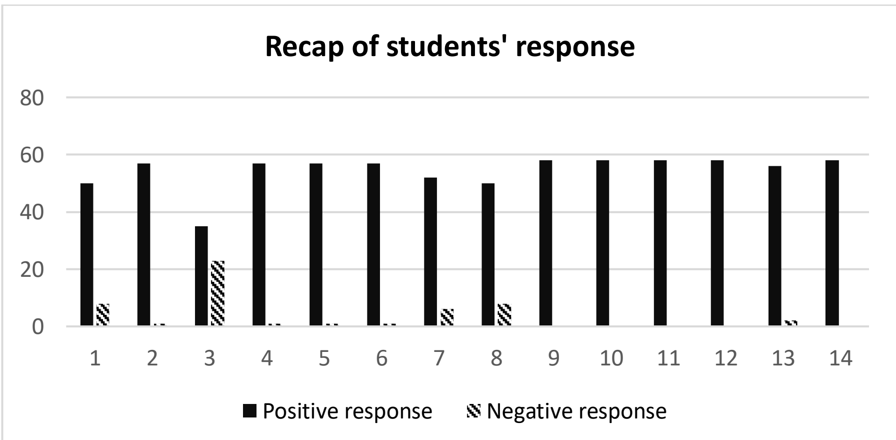

Figure 2. Analysis of students' positive and negative response on each statements

For the handbook implementation, course began with the lecturer's explanation of the topics for the practical procedure. On each experimental topic, students answered the questions provided. It was intended to support students' proposed appropriate procedures. The theoretical basis on the handbook also helped students to narrow their practicum procedures according to the purpose of the experiment. At the next week's meeting the students presented their proposed procedures and responded by the lecturer. Not all practicum procedures proposed were as expected, so the lecturer determined the chosen practicum procedures or combines procedures from several groups.

On the topic of mixture separation and purification for example, students were asked the question of how to separate one component from the mixture, what techniques can be used, and analyze the physical and chemical factors that influence the choice of separation technique. Doing the discussion by working collaboratively, students answered all questions and the lecturer gave feedback and deepened material if there were some concepts that were still not understood by students. After that students were again encouraged to look for mixture separation procedures from relevant sources namely books or journal articles.

Large scale trial implemented reflective journals. This journal was used individually on every students and aimed to be a supportive tool to examine students' progress on attain scientific literacy by performing deeper understanding and to give some information about all of difficulties or problems faced by students during their general chemistry experimental course. Many students wrote on reflective journals that they often did not understand to formulate procedure. However with the help from lab assistant, doing collaborative studying, and discussion with lecture, they finally could achieve what they expect to accomplish. Thus, average score of students' scientific literacy was 74.58, the percentage of students who get scientific literacy score more or equal to 70 is 69.23% while the remaining 30.77% have not achieved the expected minimum completeness (below 70) as illustrated on pie chart of Figure 3. The handbook was effective because more than 50% of students have attained completeness criteria. Furthermore the average score of scientific communication (presentation) was 86,5. This means that most students already have a good understanding of the chemical concepts used in laboratory activities, were able to apply these concepts to procedures, and were able to report and communicate the results well using tables, diagrams, and pictures. Therefore scientific literacy of students were in the good category.

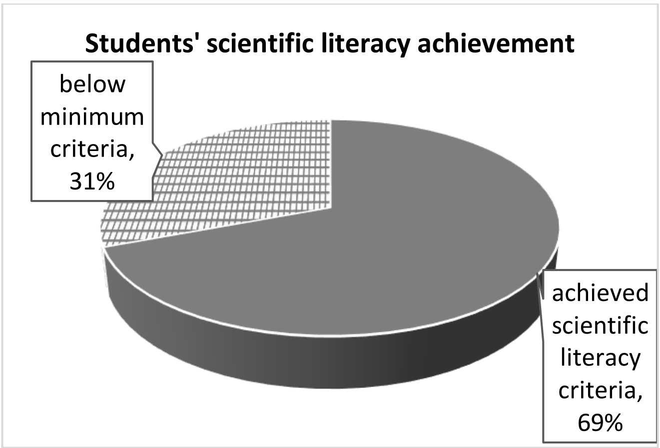

Figure 3. Classical students scientific literacy achievement (n = 58)

The results obtained was in line with research from Blumer & Beck, Husnaini & Chen, Fahyuni & Masitoh [11-13] which stated that guided inquiry on laboratory activities helped students to deepen understanding and reasoning ability. Guided-inquiry experiments provide challenges for students to determine the right procedure and search for adequate literature so scientific literacy could be promote in experiments process. It also support students' self-efficacy which students feel assure that they can accomplish tasks in efficient way. For example, students were confident to determine greener material in experiments, choosing, and using apparatus in right way according to questionnaire statement number 12, 13, and 14. Working collaboratively was also a key factor to students understanding. It facilitated students to discuss and elaborate some solutions to make modification which by doing so students develop their knowledge which contributed to students' learning achievement [14-16]

4. Conclusion

General chemistry laboratory handbook implemented guided-inquiry based on green chemistry has been successfully developed. The handbook was very valid (92,85%) according to validators' score. It was also effective to be applied on general chemistry experiment course because questionnaire from students' response illustrated positive response (93,7%) and classical completeness of students' scientific literacy was above 50% (69,23%).

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