Instructional designs to promote scientific literacy on students and teachers: a review study

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Abstract. Scientific literacy is one of the essentials literacies in twenty-first century world and 4.0 industrial revolutions. Indonesian students’ scientific literacy based on the result of PISA 2015 and PISA 2018 was not in the satisfying level yet. This study provides several instructional designs that proved could promote students’ and teachers’ scientific literacy. This review study was carried out by reviewing 15 international articles. Instructional designs that could improve student’s scientific literacy based on the studies were discussion method on scientific topic, connecting science learning with culture through personal science writing, effective argumentation on an energy-related environmental issue, literacy-infused and inquiry-based science learning, student worksheet based on education for environmental sustainable development, modified problem-based learning, project-problem based learning, pop-culture hook and authentic challenge-based learning, the differentiated instruction, structured primary literature project, teaching material based on science literacy, and STSE learning approach. Instructional designs and program to improve teacher or teacher candidate’s scientific literacy were well-constructed teacher training programs, intensive and multiple approaches teaching, instruction with Toulminian model of argumentation on the application of STEM discoveries.

1. Introduction
Scientific literacy is one of the competencies that essential for students in order to success in the 4.0 industrial revolution besides technological skills, social competencies/skills, and attitude/characters. Scientific literacy will help students enhance their personal skills such as critical thinking, analytical thinking, and problem solving mindset. The concept of scientific literacy was first introduced by Hurd in 1958. Hurd stated that scientific literacy was a decision making based on science and technology (1). Genci (1) later said scientific literacy included the ability to use scientific knowledge and scientific thinking for personal and societal objectives. Scientific literacy by Bogner and colleagues (2) was described as not only having knowledge on science but also understanding relationship between science, technology, society and environment. OECD (3) defined scientific literacy as an ability to engage with issue and ideas related to science as a reflective citizen.

OECD research, Programme for International Student Assessment (PISA), was particularly got attention from education practitioners around the world. PISA was measuring scientific literacy in teenage students around age 15. OECD explained a person that literate in science possess competencies such as explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically. Since the need of critical thinking, analytical thinking, and evidence-based
arguments in this new era, scientific literacy in students has been gathered attention to the educational practitioners.

Indonesia based on 2018 PISA’ results had level 1a in reading domain with the mean score 371, level 1 in mathematic domain with the mean score 379, and level 1a in science domain with the mean score 391(4). All of the mean scores were below OECD average mean scores which were 487-489. The results were clearly far from satisfying for the teachers and educators in Indonesia. The low level of Indonesian students’ scientific literacy can be caused by many factors. One of the factors is the instructional system in Indonesia still not effective to promote students’ scientific literacy. Many teachers used to teach students in the form of passive learning, like lecturing students. But, in recent years the government tried to change the passive instructional system into active learning system, adapting scientific method into teaching and learning process. This revolution of course is a challenge itself, either for the government, the teachers or the students.

The government and the teacher need a lot of effort in order to successfully implement the revised instructional system. The government should provide examples of active learning, manuals, training programs, and other supporting tools for the teacher. The teachers also need to change their teaching into the new form of instructional and willingly to learn many new things, which is not easy for senior teachers. The students will have various kinds of teaching and learning that different from what they used to have. Active learning required more passion in learning and relatively more effort from the students.

This review article contain various kinds of instructional that proved could promote students’ scientific literacy. The objective of this review study is to provide alternatives, inspiration, and input for the teachers to create a learning that could improve their student’s scientific literacy. The instructional designs in this review are in the form of teaching ideas, instruments, strategies, methods, models, and approaches.

2. Instructional designs that help promote scientific literacy

2.1. Instructional designs that help promote student’s scientific literacy

There were many kinds of instructional with different focus points as their goal. The type of instructional that in demand now is the one that help improves student’s scientific literacy as one of their essentials competencies in twenty-first century world, especially in the 4.0 industrial revolution. Genc (1) studied a learning method to improve scientific literacy on 30 students from grade 6th, 7th, and 8th in Turkey. The discussion method on scientific topics was chosen as the instruction. The topics were provided by researchers and different topic discussed each week for 12 weeks period. The students worked in group and reviewed the articles and took notes. The groups then expressed their views on the topic in the class. Then every week, the group interviewed the community about the topics they already discussed to compare the views of informed people with the uniformed ones. After 12 weeks, the students took test and survey to measure their scientific literacy. The result was good. The scientific literacy of the students increased significantly and the attitude toward science was more positive. Interestingly the difference between male and female students or between class levels was not significant. Thus discussion method on scientific topics could improve science literacy.

Another learning method proposed by Seraphin (5) to improve science teaching effectiveness was by connecting science learning with culture through personal science writing. The students involved were 47 students from grade 12th. Evidence from researcher’s students had shown that various writing strategies were effective in eliciting personal response and connection with science learning. These writing strategies were writing about their place and connected with its science facts, writing about learning styles and motivation they wanted, writing about their preference in learning, frequent science writing assignments from the teacher, and use culturally relevant writing prompts. Students reported that they enjoy the products of their writing and benefit from the exchange with the teacher. It was meaningful but not penalizing. Reflective science writing also crosschecked their content knowledge and could identify misconceptions. Writing also provides them to improve their critical thinking skill.
In 2018, Chen and Liu (6) investigated a learning method, effective argumentation on an energy-related environmental issue to reinforce student’s scientific literacy in Taiwan with 66 students from grade ninth. The students received instruction with topic on energy and environment to enhance their conceptual knowledge, evidence-based argumentation skill, and scientific literacy. The learning activities consist of 3 phase: 1) production of energy and utilization of electricity where students communicated their structure and utilization of batteries they brought in from of class, 2) argumentation on the usage of energy resource in the context of SSI where students made reasoning arguments about advantages and disadvantages of the batteries industries for people in Taiwan, and 3) decision-making of environmental issues in daily lives where students discussed on energy saving and carbon dioxide reduction from various aspects like clothing, transportation, and manufacture then presented the results in front of the class. Students’ conceptual knowledge, quality of the argumentation, and scientific literacy then measured by the researchers. The results of the study were positive; the effective argumentation method increased their conceptual knowledge on electricity, energy, and environment; their argument quality improved in form of perspective and coherency; their scientific literacy enhanced.

Lara-Alecio and her associates (7) made research about literacy-infused and inquiry-based science instruction to increase conceptual understanding in science. The subjects were middle school English learner students (ELs) and economically challenged students (ECs). They chose English learner students because the language in science usually information-dense, abstract, and technical, so language might be an obstacle for them to understand science. The EL and EC students were chosen because these students usually underperformed on science at the national level and state level in US. The literacy-infused and inquiry-based science instruction was in the forms of asking questions, planning investigations, developing models, and interpreting data, all while promoting language and literacy skills. They chose a teaching science concept known as The Big Ideas. The Big Ideas are organizing principles around which students can arrange facts, concepts, processes, and applications they encounter during learning. The Big Ideas related to disciplinary core ideas in the Next Generation Science Standard. They composed an assessment tool, called Big Ideas in Science Assessment (BISA). The results were: 1) there was a concurrent validity of the BISA, 2) BISA performance on post-test of the treatment group in English learner students are significantly higher after the learning process than the control group, 3) BISA performance on post-test of the treatment group in non-English learner economically challenged students are higher after the learning process than the control group, 4) there was significant and positive correlation between BISA scores and English language literacy. Based on those findings, the literacy-infused and inquiry-based science instruction could increase conceptual understanding in English learner students and economically challenged students.

The next research was conducted by Ekantini and Wilujeng (8) in Indonesia. The researcher composed student’s worksheet based on education for sustainable environment development. The study was experiment design with 60 students of junior high school in their first year, 30 student as an experiment class while 30 students as the control class. The purpose of the study was to create a valid student’s worksheet based on education of sustainable environment development to enhance student’s scientific literacy. The ESED-based worksheet theme was “water as an alternative energy source”. The ESED-based student’s worksheet was validated by 4 experts, 2 lecturers, 2 science teachers. The student’s worksheet was categorized as very good. The experiment class then received learning with the ESED-based worksheet. The gain value of scientific literacy from both classes then will be compared with the independent sample t-test. The result was the gain score from the treatment class was significantly different and higher from control class thus ESED-based student’s worksheet could help enhance student’s scientific literacy in junior high school.

Instructional can be designed not only by the methods but also by the models, the approaches, or by the learning strategies. Juleha and associates (9) from Indonesia modified problem-based learning model by adding a project onto it. The research was conducted in the private Senior High School in Bandung, Indonesia. There were 39 students purposively selected and divided into 2 classes, the experiment class and the control class. The experiment class received problem-based learning with a project and the control class received problem-based learning without a project. The problem introduced to the both
groups was human secretory diseases. The project added to the experiment class was producing an article about human secretory disease. After the learning process for three meetings students’ scientific literacy was measured. Scientific literacy of students that received problem-based learning with project was higher in score than students with PBL without project but not significantly different. Based on this result, modifying the current learning models can be an alternative to design instructional that could help improve student’s scientific literacy.

The next alternative is fresh learning strategies that really engage students: using pop-culture to gain attention and curiosity of the students. Whiley and colleagues (10) composed an instructional design using popular culture hooks and authentic challenge-based learning strategies. The research was conducted in Adelaide; Australia and the subjects were college students. The researchers used popular culture: zombie apocalypse, as a hook to engage students in learning environmental health discipline, especially in microbes and toxins topic. First, the researchers changed the subject name and description from “Microbes and Toxins” to “ENVS2741 Zombie Apocalypse: Microbes and Toxins”. The description of the subject was about survival in post zombie apocalypse world, such as providing safe drinking water, safe forage, and preserved food.

The result was really good; increased of the student’s enrolments for the subject of that year, from usually 10 students in the previous year (2016) to 26 students from 7 different degrees (2017). The learning activities in each scenario designed not only to be exciting and engaging but also facilitate the development of crucial science literacy and soft skills. The use of pop-culture hook and challenge-based learning succeed to interest students in learning environmental health, increasing their science literacy, and their soft skills. The illustration of the success was from student’s feedback after completing the subject that 100% of the students stated “agreed” or “very agreed” that the subject help developed their ability to think critically and analytically. So, these strategies can overcome the “boring” discipline and “bridge the relevance gap”(10).

Senturk and Sari (11) investigated the contribution of differentiated instruction into student’s science literacy. The research was conducted in Turkey with 23 4th grade students. The differentiated instruction approach by Tomlinson was implemented in the primary science course for twelve weeks. The differentiated instruction by Tomlinson was based on the identification of student’s interests, skills, readiness levels, preliminary learning, preferences, expectations, and learning profile. The differentiated instruction introduced by Tomlinson (2001) was reconsidered and differentiated in terms of the content, learning-teaching process, learning outcomes, and assessment items. The result was the differentiated instruction contributed to science literacy in several sub themes: relations with science, relations with technology, relations with society, relations with the environment, and scientific process skills.

The students expressed in their diary on the sub theme “relations with science” that they were more interested in science with differentiated instruction, they learned while had fun and they sought to use the scientific knowledge they acquired in everyday life. On the sub theme “relations with technology”, students expressed they were more interested in technology with differentiated instruction, they made more use of technology tools and materials in lesson and everyday life, they also created technological tools during the process. On the sub theme “relations with society” the students stated that they carried out various activities by interacting with society like parents first and then other people, because of the differentiated instruction. On the sub theme “relations with the environment”, students became more aware about the environment and wanted to improve the environment. On the sub theme “scientific process skills” it was revealed students used the different knowledge gained from investigation and research on various topics during the process. The scientific process done by students that observed by the researcher was developing hypotheses, doing observations, investigations, experiments, interpretations, and developing suggestions(11).

The next learning model to improve scientific literacy is the structured primary literature project. Eslinger and Kent (12) conducted researches in New York, United State of America with 550 undergraduate students from humanities major that took biology course. They wanted to improve student’s scientific literacy through structured primary literature projects. The course consisted of 40 lessons and 8 laboratories and during the courses students were required to select and analyze one
primary literature article within the group consisted of two or three students. The project was divided into four parts: 1) selection of article; 2) written analysis; 3) submit slide presentation; 4) communicating the result by presentation. The data was collected using Academy Management System, an internal Academy grading system where the instructor entered the scores for selection and verification of primary literature (10 points); written analysis (125 points); slide upload (5 points); slide assessment (50 points); and oral presentation (30 points). The results were the students that followed the guidance and assessment metric scored very well, the average scores of selecting article 92.4%, written analysis 90.7%, slide upload 99.1%, slide assessment 93.3%, and oral presentation 91.6%. The feedback from the instructor regarded the literature project to improve student’s scientific literacy and critical thinking skills also positive, ranged from agreed to strongly agree. The feedback from students regarded the literature project to increase their scientific literacy and critical thinking skills also positive mostly ranged from agreed to strongly agree.

The design of instructional in order to promote scientific literacy also can be viewed from the teaching materials. Avikasari and colleagues (13) designed a teaching material based on science literacy to influence students’ science achievement. The teaching material was in the form of a textbook designed according to the 2013 curriculum in Indonesia. The science literacy-based teaching material contained four categories of science literacy, such as science as body of knowledge, science as an investigating tool, science as a way of thinking, and interaction of science, technology, and society. The research was conducted in Semarang, Indonesia with 46 fourth grades students. The science achievement was assessed with 30 multiple choices items before and after the learning process. The average pre-test score was 39.94 while the passing grade was 60. After students learned with scientific literacy-based learning material, the average post-test score was 66.89 which surpassed the passing grade. The comparison on pre-test scores and post-test scores with the dependent t-test showed there was significantly different scores after the learning process. The finding indicated that scientific literacy-based learning materials can improve students’ science achievements.

Chanapimuk and colleagues (14) studied the science, technology, society, and environment (STSE) learning approach to improve students’ scientific literacy. The research was conducted in Thailand with 35 students from grade 11. The study consist of 3 cycles, each cycle consist of 4 phase: planning, action, observing, and reflect. The environmental issues presented in the class were as follow: 1) the effect of using chemical insecticide and GMOs plants; 2) the effect of using chemical coating in corn seed; 3) the effect of using chemical plant growth hormones on banana planting. The learning activities were motivation by the teacher, group discussion, group exploration, brainstorming, and presentation. The students’ scientific literacy assessed with the modified instrument based on PISA instrument with 3 competencies measured: explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically. The result from the research was the STSE approach improved students’ scientific literacy. The level of scientific literacy before learning was 3, after 3 cycles increased to 6 and in the posttest it become level 5. The level of scientific literacy after cycle 3 was highest possibly because during the cycle they worked within the group so there was collaboration and confirmation among the group members to help each other and increase their scientific literacy. The researcher suggested that group collaboration also could help to improve students’ scientific literacy.

2.2. Instructional designs that help promote teacher or teacher candidate’s scientific literacy

Teachers as the facilitator, mediator, and other supporting roles for the students need to set models for the students. Teachers in order to help students enhance their scientific literacy need to literate in science itself. There were some studies that measured teacher or teacher candidates’ scientific literacy and some treatments that could help enhance their science literacy. Zhang and colleagues (15) published an article of longitudinal research on the scientific literacy of primary science teachers in the ten year change. The researchers tried to investigate the development and changes of the scientific literacy of primary science teachers after ten years. The sample was the primary science teachers from 21 provinces in China in 2003 and 2013. The questionnaire for assessment consisted of five parts: the demographic and
sociological of respondents, the procedure knowledge of science, the classic view on the nature of science, the contemporary view on the nature of science, and the inquiry teaching behavior. The nature of science is agreed to be critical elements for developing scientific literacy of a person.

The results were as followed: primary science teachers consisted of 35.4% man and 64.6% woman, with the changes of scientific literacy: procedural knowledge and classic VNOS were increased statistically, and the teaching behavior was still the same. Another result was that the teacher training programs had no correlation with procedural knowledge and teaching behavior but had correlations with their views on NOS. The training was effective to improve the contemporary VNOS of the teacher(15). Based on this study, we can conclude that training programs were effective to change teacher’s views on the nature of science but not to change knowledge and teaching behavior. This could be important feedback to the government in order to create more effective training programs for the teacher.

The education obtained by the teacher also took part in the teachers’ science literacy. Ecevit and colleagues (16) studied the views on the nature of the elementary school teacher candidate in Turkey. The research was conducted in 2015 with the subjects were 65 third-year elementary teacher students at University in Ankara, Turkey. The students received intensive, multiple approaches teaching to understand the nature of science for 9 weeks course. The learning activities involved were historical approach activities, generic activities, explicit-reflective approach activities, and media news analysis activities. Student’s knowledge and understanding about NOS and basic scientific concepts were assessed with the Science Knowledge Survey (SKS). There were 5 themes of NOS that assessed on the students: The tentative nature of scientific knowledge, the dependence of scientific knowledge on experimental evidence, the subjectivity of scientific knowledge, the role of imagination and creativity in science, and general view. Before interventions around 65-76% of the teacher students were categorized as naïve and 3-35% categorized as transition and 0-1% as informed in those five themes of NOS. After the intensive interventions, the naïve category significantly decreased (5-13%) and the transition (23-65%) and informed category (29-64%) were increased in those five themes if NOS. This finding indicated that the views on the nature of teacher major students were improved by the end of the intervention. The SKS score then compared before and after treatments or interventions, there was significantly different result before and after interventions, mean that the learning approaches and activities used improved the teacher students’ views on the 5 themes of NOS.

Another research on teacher candidates was conducted by Toth and Graham. The research was conducted in The United Stated with 14 female, pre-service elementary school teacher candidates. The candidates received instruction with Toulminian model of argumentation for the logical examination of information in order to enhance their critical thinking skills. The topic was news about the application of STEM discoveries. The activities had four phases: 1) introduction and guiding question regarding the SSI, 2) examination of background information, 3) collaborative work groups session one, 4) jigsaw and collaborative session two. There were two findings in this research; candidate’s interpretation on conflicting perspectives and candidate’s integrating of evidence from multiple sources. The candidate’s interpretation on socio-scientific issue from four perspectives were as followed: the rational reasoning on medic and reporters perspective was highest than emotional and intuitive reasoning; the emotional rationing was most used on local business and people perspective, followed by rational reasoning and intuitive; the rational reasoning also used very often followed by intuitive reasoning in government perspective with emotional as the lowest; for the personal perspective they used intuitive reasoning the most followed by emotional and rational reasoning. The result for candidate’s integration of information from news media: the candidates used all the arguments elements such as claim, evidence, backing, warrant, limitation, and qualifier but they not quite succeed to make connections between them. They tend to make one-to-one connections instead of multiline connections, in form of top-down or circular structures. The candidates mostly correct when used factual evidence and historical evidence from the news to create arguments(17). Based on these findings, it can be said that using normative and logical thinking when criticize news could improve teacher candidates’ critical thinking ability.
3. Discussion
Scientific literacy is not consists of science alone, there is more than science knowledge involved to construct a person’s scientific literacy such as literacies in technology, mathematic, and information. Based on these studies already described, when teaching science to the students, some of the research used topics related to the environment or and social issues. Topics on environmental and social issues not only as a means to improve science literacy but also to raise awareness of the issues have become additional goals of the learning.

In order to understand and comprehend the environmental and social issues happening around them, there are several abilities students need to possess, such as abilities to choose the informational and reliable news or articles; and abilities to think logically and critically upon the information provides by the news or articles. These are the examples of information literacy. The soft skills of information literacy are in line with the soft skills of science literacy, thus information literacy could be a support to the students when improving their scientific literacy. Furthermore, information literate students will be able to choose the right scientific literature when learning science. The problem is science teachers rarely explain to the students on how to obtain or evaluate reliable and informational sources, materials, or articles when learning science.

Klucevsek (18) wrote that it was important to always review the literature and search for new conversations while asking questions, designing experiments, analyzing data, and doing research. Klucevsek stated that most of her students didn’t know about publication process behind articles they found. Without knowing how article was published it was difficult to determine the type of scientific literature and use them ethically. Information literacy was an important part in understanding science as a process, and therefore science literacy. It is then become a challenge for the schools and the teachers to educate their students about information literacy.

4. Conclusion
Scientific literacy as one of the essential literacies in twenty-first world and 4.0 industrial revolutions should be possessed by students. In order to help students improve their scientific literacy through instructional, teachers should possess scientific literacy and provide students with appropriate learning. Instructional designs that could improve student’s scientific literacy based on studies discussed above are as follow: instructional with discussion method on scientific topic; instructional that connecting science learning with culture through personal science writing; instructional with effective argumentation on an energy-related environmental issue; literacy-infused and inquiry-based science instruction; student worksheet based on education for sustainable environment development; modified Problem-based learning, Project-Problem based learning; pop-culture hook and authentic challenge-based learning, the differentiated instruction; instruction with Toulminian model of argumentation for the logical examination of information on the news about the application of STEM discoveries.

There are also some instructional designs and programs for teachers or teacher candidates to improve their scientific literacy. The instructional designs are as follow: well-constructed teacher training programs; intensive, multiple approaches teaching such as historical approach activities, generic activities, explicit-reflective approach activities, and media news analysis activities; instruction with Toulminian model of argumentation for the logical examination of information on the news about the application of STEM discoveries.

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