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What is your chemical creation to overcome environmental pollution? Students' creative ideas on the RADEC learning model

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Abstract

This study aims to increase student creativity on environmental issues such as pollution by implementing the RADEC learning model. The study used a one-shot case study method with 25 7th-grade participants. Student worksheets, observation sheets, and interviews served as tools. Those instruments were used to track the development of their creative ideas during science classes. This data was triangulated for representative results. The results show that the RADEC learning model promotes student creativity. Students have come up with many ideas related to pollution solutions. Before and after the implementation of RADEC, students presented a considerable number of ideas. Most of these were dominated by posters that persuaded readers to keep the environment clean and use alternative energy. Some of them produced water purifiers, natural fertilizers, and solar ovens. Some of them showed the chemical concept of solidification of impurities. Although these ideas were not originally born and did not show many of the chemistry concepts, students were able to create solutions directly and showed fluency in reasoning.

Keywords: *Fundamental chemistry concept, Environmental pollution, Pre-learning questions.*

1. Introduction

Creativity is one of the 21st-century skills needed in the field of economics and plays a major role in students' career development in the future [1, 2]. The Partnership for 21st Century Skills (P21) states that creativity and innovation are two exceptional earning skills that must be possessed by students [3]. The Assessment and Teaching of 21st Century Skills (ATC21S) categorizes creativity and innovation as ways of thinking that students must have to be successful in facing the future [4]. The Organization for Economic Co-operation and Development (OECD) and several other frameworks also map creativity and innovation as the key to achieving future success and must be combined with digital expertise in the 21st century [5-7]. Creativity is an unlimited and universal skill in various fields, including science education, so it is mandatory to be trained and developed in classroom instructions. Sukardi et al. [2] and Siregar et al. [8] reveal that although creativity is not the main goal of learning in secondary education in Indonesia, the teachers have shown great enthusiasm in training and developing students' creative thinking skills. Siregar et al. [8] said that even under stress, creative thinking skills can produce creative products if students are trained and developed properly. Although it takes time, creativity can be taught optimally by considering supporting factors and eliminating inhibiting factors [9]. One of them is to provide space for students to carry out guided practice in a constructive learning environment [10]. So basically, teachers need structured hands-on and minds-on learning activities. Innovative teaching strategies are the key to building students' creativity. The results of the research by Sukardi et al. [2] and Sopandi & Handayani [11] show that innovative learning strategies chosen by teachers require adjustments to student conditions and the Indonesian curriculum. Students have to be concerned and responsible for the environment. The data showed that there have been destructive and very massive environmental changes caused by human activities [12-14]. Sopandi and Sukardi [15] even compiled data from various sources showing that the quality of bodies of water in Indonesia is very poor. They explain that the transfer of waste from land to bodies of water is caused by natural phenomena, such as the movement of water from upstream to downstream or ocean currents that mix garbage in the ocean into a homogeneous state. These natural phenomena will not synergistically support waste transfer if humans manage waste properly. Teaching materials require a creative teaching process so that students can provide creative solutions in the form of products in environmental pollution. Pre-learning questions related to the concept of chemistry are created by Sukardi et al. [16] and should be asked to students throughout the pollution class. Solid, liquid, and gaseous pollutants move, the effects of organic and inorganic fertilizers on air composition, the effects of pesticides on water areas, acid rain processes, the effects of oil spills on aquatic organisms, deforestation on air quality impacts, river waste management, factory chimney filter soot, the impact of increased greenhouse gas emissions on global warming, and reduced greenhouse gas emissions through the use of alternative energies are all fundamental chemical concepts on environmental pollution. As one of the countries that supports the 2030 Agenda to realize sustainable awareness in the environmental field, Indonesia pushes for an educational approach that is needed in the education for sustainable development (ESD) framework. Through education, students' creativity is expected to prevent massive damage to the earth. Water pollution, air pollution, global warming, ozone hole leakage, and climate change are materials that students should understand. However, several reports show that learners' (elementary students and secondary school students) understanding has yet to be improved so that they can manifest creativity and sustain environmental awareness through science education [17-19]. In the Indonesian context, the instruction of the materials must be able to build fundamental science concepts, creativity, as well as sustainable awareness. Teaching strategies that stimulate students to think creatively are generally project-based or problem-based learning models. These learning models are typical for students who have a good reading culture and scientific literacy. In the Indonesian context, students should be given learning activities that require them to read with comprehension materials related to environmental issues. This step is expected to inspire students to formulate problem solutions.

Several studies provide information that students need a process to think creatively, one of which is through critical discussion which asks students to always complete an argument with reasons or evidence [2, 8]. The RADEC learning syntax (*Read – Answer – Discuss – Explain – Create*) is one of the learning models that can accommodate these needs. Previous research has shown that the RADEC learning model was able to improve conceptual mastery and stimulate creative thinking skills of high school or vocational students. They can make various products such as bioplastic, aromatherapy candles from petroleum, and even organic paints from nature [8, 20, 21]. Students' ability to make products is supported by a good understanding of chemical concepts. This is because each RADEC learning model syntax has many roles, ranging from building students' scientific literacy, reading comprehension, conceptual understanding, cooperation, and communication, to critical thinking skills which are the basis for developing students' creative thinking skills. Previous research has focused on highlighting students' creative work related to teaching materials at the secondary school higher level and vocational school. Meanwhile, research that can stimulate creative thinking of lower-level secondary school students on making products that save the environment has not yet been done that much, especially those involving chemical concepts. The teaching of chemistry concepts at the secondary school lower level has so far been at the stage of recalling information that has not yet touched the realm of high order thinking such as creative thinking. Several studies have shown that creative ideas in making products are strongly supported by reading comprehension and digital-science literacy activities [22]. This study aims to see the impact of RADEC model implementation on students' creative thinking skills as well as their creative ideas to overcome the problems of environmental pollution. RADEC learning steps facilitate students' understanding of fundamental science concepts. Furthermore, through the *create stage*, the teacher stimulates students' creativity to convey ideas for making creative products based on sustainable awareness of the environment's future on earth. The research applied a one-shot case study design that investigated the impact of the RADEC learning model on students' creativity and creative thinking skills. Research data were obtained through several instruments such as students' worksheets, observation sheets, and interviews. After the data collection, these were, it is processed descriptively with triangulation techniques to get representative results. The research questions of the research are:

(i) How does the worksheet feature promote student creativity?

(ii) What are the students' chemical creative ideas for overcoming pollution problems?

2. Water Purification: Filtration and Coagulation

Sukardi, Sopandi,and Riandi [16] stated that alum is one of the content students must learn. Alum is often used as a chemical in water purification, so local water companies are no exception. The steps of treating dirty water and keeping it clean go through the steps of neutralization, coagulation, precipitation, and filtration. It is hoped that these efforts will enable the safe and sanitary use of clean, contaminated water. The first step is neutralization. This helps to adjust the acidity of the water to neutral (pH 7-8). For acidic water, such as peat water, the cheapest and easiest way is to give lime. The second stage is to sprinkle alum into the water so that the impurities in the water are in the form of suspended solids, such as organic dyes, fine mud, and bacteria so that they can agglomerate quickly. Alum is a common coagulant and is also a general term for various aluminum compounds. Alum is sometimes seen in its crystalline form, although it is most often a powder. It can be used for water purification. The process of coagulation takes place in water, as shown in the chemical reaction (1):

$$Al_2(SO_4)_3.18\,H_2O + 3Ca(OH)_2 \rightarrow 2\,Al(OH)_3 + 3Ca(SO_4) + 3CO_2 + 18H_2O \quad (1)$$

The third step is the separation process, which ends with a filtration process by draining the adhering water into a sand-filled filter pan. The cleaning method is the easiest and easiest to perform. As science evolves, the chemicals used to purify water are becoming more diverse, as is the complexity of pollutants.

As long as students understand the basic concepts, designing and building a water purifier is not that difficult. A study by Alsultan et al. [23] shows that secondary school higher-level students can do this. Students make sure that the water coming out of the device can be safely used for hygienic purposes. It is named *biosand filter for water purification* as shown in Figure 1.

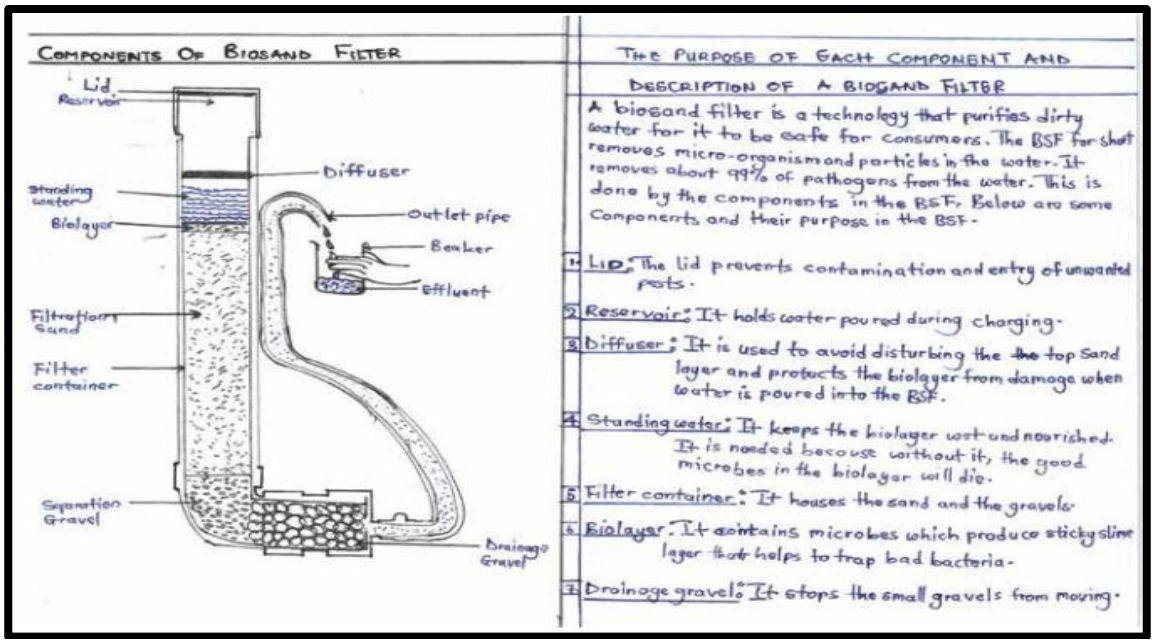


Figure 1. Student's design of biosand filter for water purification [23]

In addition to alum, there were zeolite powder and chitosan. The adsorption capacity of zeolite powder is suitable for heavy metal removal by ion exchange due to its interconnected porous structure and chemical properties. On the other hand, adsorption of soluble organic dyes from water using a squeezable "sponge" made of chitosan aerogel [24]. Figure 2 shows the chemical formula of chitosan and how it works as a purifier. Part a of Figure 2 shows the origin and chemical formula of chitosan. It also provides a detailed representation of the chitosan aerogel polymer network and also provides interactions with dye molecules. In Part b of Figure 2, you can see a simplified representation of the chitosan network and pigment interaction, and in Part c you can see the corresponding cartoon-style diagram.

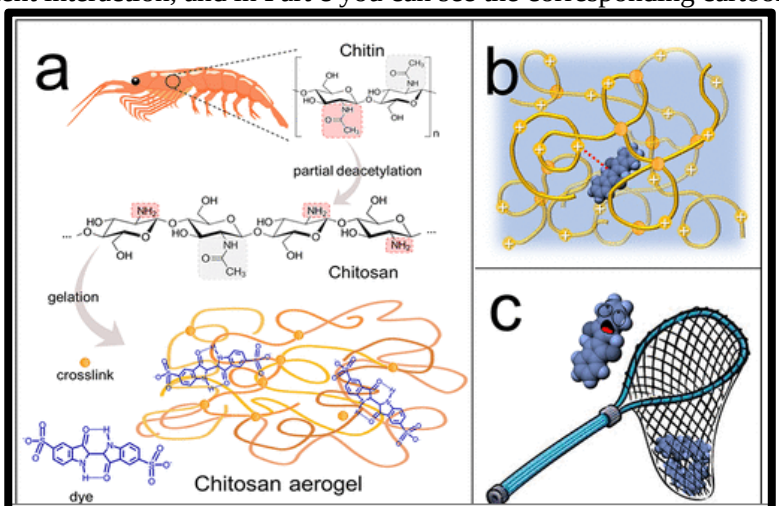


Figure 2. The chemical formula of chitosan and how it works as a purifier [24].

Figure 3 shows how zeolite can purify water containing heavy metals. Figure 3a shows copper (II) nitrate dissolves in water at a concentration of 10 g / L, resulting in a light blue solution. Choosing a colored salt is essential to make the cleaning process easily recognizable. Figure 3b shows the addition of zeolite powder (about 2 g in a 50 ml solution) to the solution and the shaking of the vial vigorously. Leave the whitish suspension. This time frame describes what happens in the system at the molecular level. Cu^{2+} ions in water are replaced by Na^{+} cations belonging to the zeolite framework after the so-called ion exchange process. Contextually, the sedimentation of zeolite particles is caused by gravity. A phase separation system can be obtained in minutes. The upper aqueous phase is transparent, indicating that the concentration of copper ions is negligible. Figure 3c shows the bottom of the vial contains a zeolite powder containing metal ions, as evidenced by the color change from white to light blue. Finally, the removal of the zeolite powder by filtration completes the repair protocol. To show the possibility of reusing such materials, the possibility of regenerating zeolite particles will also be discussed. Also note that in this regard, the regeneration of zeolite powder, which replaces copper ions with Na^{+} species, can be safely carried out with 0.1 M NaCl.

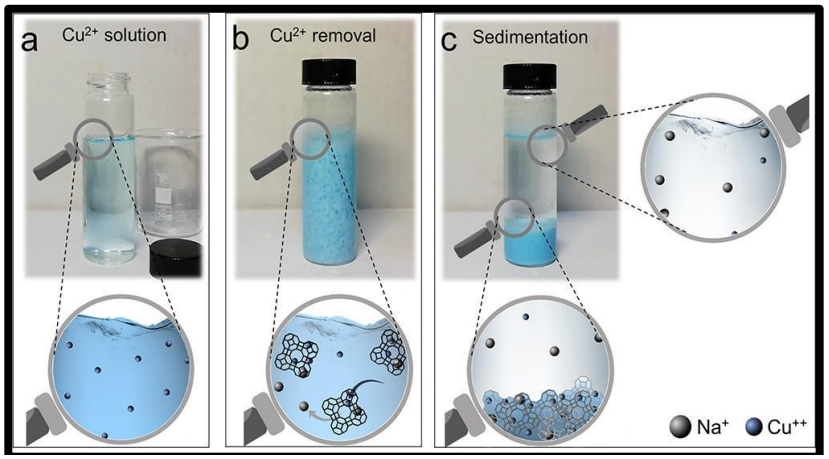


Figure 3. How zeolite can purify water containing heavy metals (Cu^{2+}) [24].

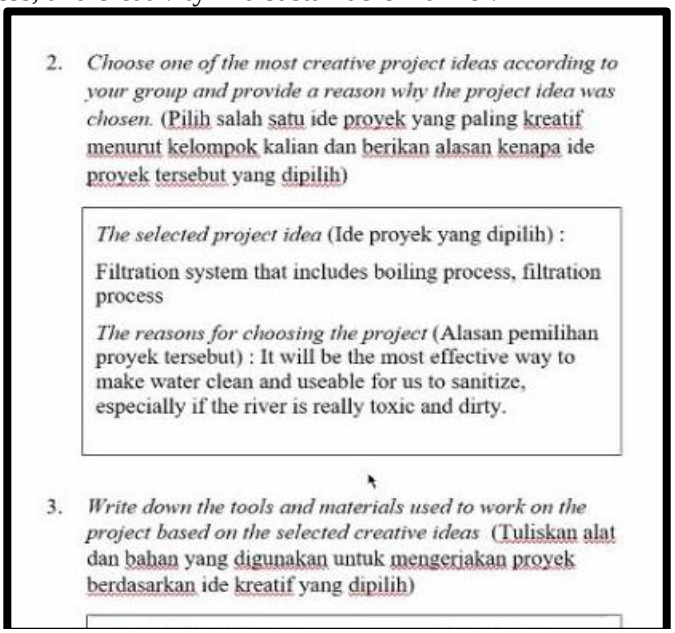
3. Methods

This research implements a *one-shot case study* design that looks at the effect of implementing the RADEC learning model on students' creativity in solving environmental problems. A one-shot case study is a simple quasi-experimental design that looks at the effect of a treatment on a variable globally, it is appropriate for this research that is looking for the general effect on model learning implementation [25]. Participants in this study are 25 students of secondary school grade 7 in Bandung. Meanwhile, the instrument used is the student's worksheet which contains the creative ideas of all students in each group regarding the solution to pollution. The creative ideas are then classified based on their originality. The worksheet contains a question column that investigates the student groups' answers related to the selection of ideas in making creative products to the steps for processing them. In addition, unstructured interview questions and observation sheets are used to investigate the findings of the study. The collection of worksheets uses the *google form* platform as classroom instruction is entirely online. All interviews are also carried out through *zoom cloud meetings*. The data are analyzed narratively and then triangulated with student interview results and field notes during classroom instruction.

4. Results and Discussion

4.1Description of student's worksheet

The student's worksheet contains several questions asking the ideas of each student in the group, the group's creative ideas to make a creative product, the tools, and materials needed, and the steps of the production process. The following figure is a display of the student's worksheet. Figure 4 shows that the worksheet is used to collect all students' ideas, even though only one idea will be selected for the group's project. Indirectly, the large selection of ideas stimulates students to build creativity and practice their scientific analytical skills. These choices are used as sources of inspiration for students. The answer choice that serves as an example, as well as inspiration, is a simple water purifier which is a tool that is packaged as a solution to a socio-scientific issue. Through this context, it is hoped that not only creative ideas will emerge but also the environmental awareness of students [26, 27, 28]. RADEC learning syntax with contextual learning topics can meet the students' needs to understand fundamental science concepts while building creativity and social awareness. These results are obtained based on the results of interviews with several students who share their experiences. RADEC's learning model builds the fundamental concept of science, environmental awareness, and creativity in a sustainable manner.


2. *Choose one of the most creative project ideas according to your group and provide a reason why the project idea was chosen.* (Pilih salah satu ide proyek yang paling kreatif menurut kelompok kalian dan berikan alasan kenapa ide proyek tersebut yang dipilih)

The selected project idea (Ide proyek yang dipilih) :

Filtration system that includes boiling process, filtration process

The reasons for choosing the project (Alasan pemilihan proyek tersebut) : It will be the most effective way to make water clean and useable for us to sanitize, especially if the river is really toxic and dirty.

3. *Write down the tools and materials used to work on the project based on the selected creative ideas* (Tuliskan alat dan bahan yang digunakan untuk mengerjakan proyek berdasarkan ide kreatif yang dipilih)

Figure 4. Excerpt of student's worksheet

This worksheet is designed to train students to design products based on the EDP (Engineering Design Process). Students made the design by using kinds of drawing software, others used hand drawing. This product starts with an inference question using the question "reason". This question is designed to allow students to learn about the audience they are designing through observations and interviews. Also, consider who the product user is and what is important to that person. Meanwhile, teachers continue to emphasize that the products students create, based on observations made during learning activities, are useful not only for the environment but also for the economic, social, and cultural lives of the increasing members of the community. An interesting student answer was obtained for this question. The student replied that they would use hair instead of the "palm fiber" of the tool they wanted to make, so the water purifier they made would also bring financial benefits to the barber. The teacher then asks the student about the size of the particles that can pass through the filter. The students briefly explained that the water stains were "tied" to the hair. Unfortunately, the students could not explain the chemical process that took place. Worksheet questions are general questions that do not test a student's understanding of a particular chemical concept. Sujana et al. [29] showed in their research that a student's understanding of the basic concepts of chemistry develops when pre-learning questions include chemical representation. This chemical expression includes macroscopic, sub-microscopic, and symbolic

representations. The results of interviews with 10 students showed that only 1 student understood chemical reactions as the key to the water purification process. Meanwhile, others still think that the water purification process is a simple filtration related to the size of the solute particles in the suspension.

4.2. Students' creative ideas to overcome pollution problems

Before starting the discussion stage, the teacher gives some questions, which are related to the process of separating mixtures. These questions are asked as pre-learning questions given to students at the *Read and Answer* stage. Besides, these questions are also given to stimulate students' arguments regarding the carbon footprint. Students' ideas to deal with the problems of environmental pollution are dominated by making posters containing persuasive invitations to implement environmental awareness as shown in Figure 5.

Figure 5. Students' creative ideas in making posters

Besides making posters, other creative ideas are also found, such as making crossword puzzles with environmental content, writing song lyrics that encourage people to love the environment, ideas for making water filters with materials around students' neighborhoods, and solar stoves to boil water. The results of interviews with students show that the idea of water filtration emerged because of the student's observation that many rivers in West Java are very dirty due to garbage. This is supported by several data claiming a massive decline in river water quality in recent years [15]. This is also supported by several reports for the adsorption process [30-32]. Students understand that there must be active chemical substances that absorb harmful chemicals in the water filter equipment that they design. Generally, they understand how chemical substances work by reading descriptive texts from various sources, both textbooks, and websites. However, they do not yet understand how these active substances work in absorbing harmful chemical substances. Besides, students also often mention that to purify water, they can use chemicals that can coagulate harmful substances. Some of them make an analogy that dirt would be trapped in colloids such as various types of toppings contained in a jelly cup as shown in Figure 6. The process of water purification understood by students is coagulation. Particles that cause cloudy water that cannot be precipitated through a physical process can be precipitated by adding chemical substances. Secondary school students are not familiar with IUPAC names because they are more familiar with trivial names. Some examples of familiar coagulants are Pollyaluminium Chloride (PAC) and Aluminum Sulfate. Students will be more familiar with the name alum compared to Aluminum Sulfate which has the chemical formula $Al_2(SO_4)_3.18H_2O$.

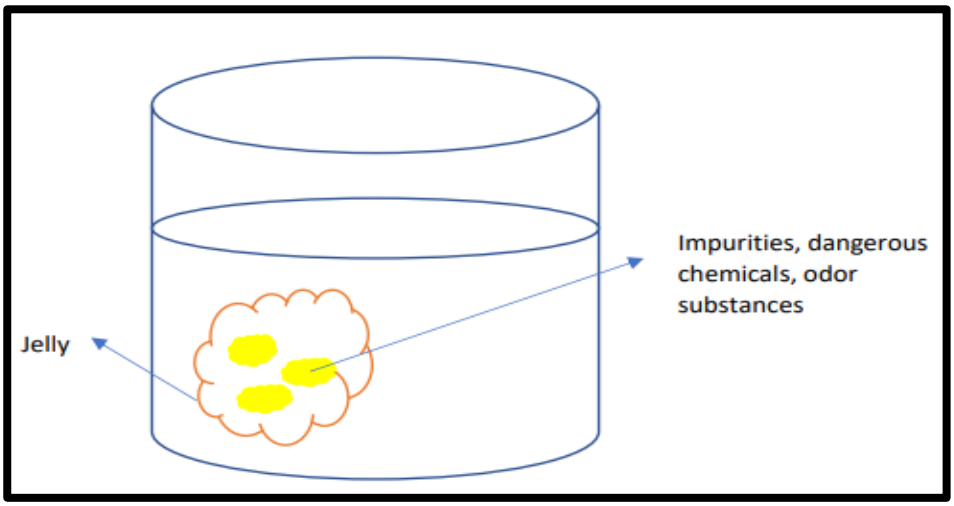


Figure 6. How chemical works using the coagulation process in water purification based on student's drawing

The results of interviews with 25 students showed that alum remains the most popular water purification chemical. The next ingredient that is popular with students is chlorine. Zeolites and chitosan are two chemicals that students also refer to as water purifiers, but students do not understand in detail how these two materials can purify water. Students can find reviews of these two materials on the internet. However, based on worksheets produced by the group, students understand that the water purification process generally consists of two phases: the physical separation process, filtration, and coagulation with chemical reactions. The complete information on students' answers is shown in Figure 7. They were students' answers on water purification. Students can answer more than once except for the principle of purification. They got the information from the internet through random sources on websites. Drinking water contaminated with heavy metals usually has three types of heavy metals, which are classified according to how dangerous they are to our bodies. The most dangerous heavy metals are lead (Pb), mercury (Hg), cadmium (Cd), copper (Cu), and zinc (Zn). They tend to be hard to understand for students because they have not seen those heavy metals. However, from the results of student interviews, iron (Fe) is well known as a heavy metal that pollutes drinking water. It is indicated by relatively yellowish watercolor and bad odor and causes rust or corrosion. Once they only remember the chemical reaction of how iron (Fe) and oxygen (O_2) are reacted in nature. They have not known the chemical formulation and the process of ion exchange.

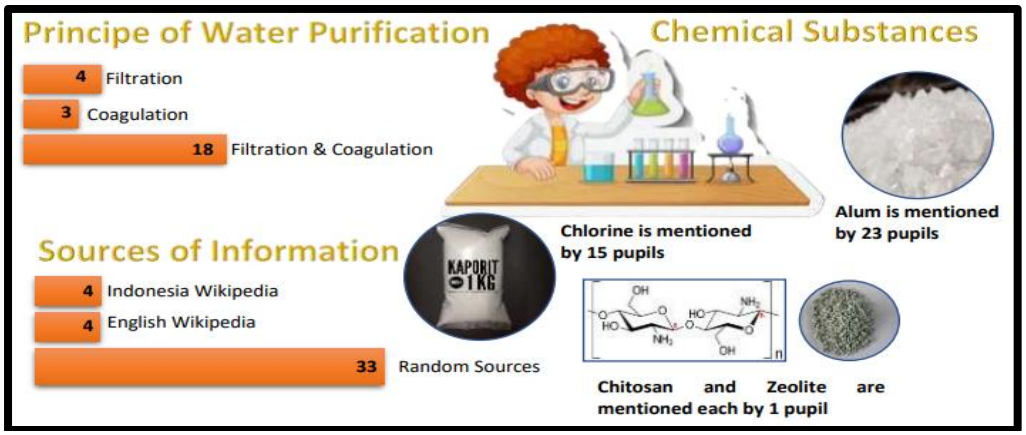


Figure 7. Students' answer on water purification.

Meanwhile, ideas to solve air pollution are also dominated by posters containing measures to reduce greenhouse gas emissions. They selected to use alternative energy such as solar energy, such as one group of students who chooses to make a stove with solar energy. This is because the concept of alternative energies has been well studied by them in school [33-36]. However, in the process, students who initially planned to create their creative products did not realize their ideas into products because of the limitations of meeting and direct interaction. Students understand that sunlight is not only a source of light but also the biggest source of heat for the earth. They mention it is related to solar cells but when further confirmed they have limited understanding of it. They say that the heat energy in the sun can be accumulated and stored so that it can become an electric stove. The process of making a solar cooker is also relatively easy [37]. One of the students said that the principle of the solar cooker is similar to the greenhouse effect. The concept is not right at all. Students need more explanation of the concept. When analyzing the novelty and originality of students' ideas, especially in creative products, some of these ideas can be easily found in various printed and electronic sources. However, an important finding from this learning process is not only the originality of the students' creative products but also the students' ability to analyze problems and find solutions. The student's worksheet used in the RADEC learning model directs students to look at scientific problems as a whole so that they can make more focused decisions to change the system of thinking more effectively. Data related to students' creative ideas for overcoming pollution are presented in Table 1. Posters still dominate students' creative ideas, which indicates that although the RADEC learning model has been able to stimulate students' creativity, it still needs improvement because their creative ideas are still in the conceptual idea stage. Although students' ideas are still in the conceptual idea stages, the implementation of the RADEC learning model stimulated students to think creatively. They showed fluency in thinking that did not appear before the implementation of the RADEC learning model. RADEC learning model opened opportunities for students to have reading comprehension and earned many ideas including some unintended knowledge. Table 1 shows that many ideas that appeared after the implementation of RADEC were also some common ideas that could be found on the internet. It showed that the RADEC learning model compelled students to read and be focused on the content of the lesson. With more ideas, students have more choices on environmental solutions. Table 1 also shows that there was a significant improvement in students' ideas about overcoming environmental pollution.

Table 1. Students' Creative Ideas in Overcoming Environmental Pollution.

No.	Creative Idea	Before RADEC	After RADEC
1	Posters with content asking to reduce carbon footprint	10	15
2	Posters with content guiding steps to reduce environmental pollution	7	12
3	Water purification product with a simple filtration principle	5	12
4	Water purification product with coagulation principle	0	8
5	Making compost	0	6
6	Solar-powered stove	1	5
7	Composing songs to increase environmental awareness	2	4
8	Making crossword puzzles to improve understanding of concepts related to environmental pollution and global warming	1	3
	Total	26	65

Table 1 shows a significant increase in ideas and projects for creative actions to solve pollution problems. However, it does indicate that most students choose to create a poster. Five groups have decided to work together to make a simple water purifier from used materials such as bottles of mineral water and cans of paint. One of the barriers students face when working in online groups is the limited mobility to get together. This causes some group members to work individually on the group project. Interestingly, when researchers asked all the members of the group, they said that they needed to make a water purifier and a dust filter urgently to maintain the quality of water and air.

Conclusion

The results show that the RADEC learning model can develop students' creativity. Students produced many ideas related to the solutions to pollution. Most of them are dominated by posters that persuade the readers to keep the environment clean and to use alternative energies. Although these ideas were not originally born and did not show many of the chemistry concepts, students were able to create solutions directly and showed fluency in reasoning. This is the proof that RADEC learning model stimulates and builds students' fluency and thinking skills.

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