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Enhancing grade eight students' creative thinking in the water STEM education learning unit

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ABSTRACT

Water issues, a commonly discussed issue in water STEM education, present students with a challenge to put their engineering design skills to the test in a STEM project. This study aimed to enhance and examine Grade 8 students' creative thinking in the water STEM education learning unit. It involved purposively selected 45 eight-graders enrolled in a school situated in Khon Kaen, Thailand. The study was carried out in three weeks which equate to twelve hours of learning covered in six lesson plans. Applying the interpretive paradigm, this study adapted Barak and Doppelt (2000)'s Creative Thinking Scale (CTS) to assess students' applying knowledge and creative thinking. The findings likely demonstrated that most of the portfolio elements might be interpreted for the attainment of creative thinking in layers of awareness, while some others could be viewed as layers of observation, strategy, and reflection. This paper clarifies what and how students' projects could be interpreted in each layer of creative thinking. Further implications for setting up STEM education in the school setting are proposed.

Keywords: creative thinking, project-based learning, STEM education

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INTRODUCTION

A strong educational foundation for youths is inevitably required to develop the highly skillful talent of countries. The primary goal of the Science, Technology, Engineering, and Mathematics Education (STEM education) agenda provided the issues of improving the proficiency of all students in STEM, irrespective of whether they choose to pursue STEM careers or postsecondary studies, while fostering 21st–century skills (Marginson et al., 2013). Fostering such skills, including critical thinking, problem-solving, creativity, collaboration, self-directed learning, and scientific, environmental, and technological literacy, was identified as being crucial for success (DeCoito, 2016; DeCoito & Richardson, 2016).

STEM education has been pushed to improve education in the early twenty-first century. However, the leaders and educators in each country held varied beliefs, focuses, and actions of STEM education. These included STEM educational reform, preparing for STEM workforce and STEM literacy, structuring STEM as a track of school curriculum, providing a broad range of content and practices, exploration of different teaching strategies for STEM, teacher preparation for STEM education teaching approach (Barlex, 2009; Bell, 2012; Bybee, 2013; Herschbach, 2011; Kim, 2011; Marginson et al., 2013; Ritz & Fan, 2015; Sanders, 2009; Williams, 2011; Sutaphan & Yuenyong, 2019). Internationally, many foundations have been established by the government, schools, and enterprises to foster STEM education and communications. The new ways of integrating content and practices among technology, engineering, science, and mathematics were organized. This generates the principles to enhance student learning of complex concepts. The hands-on nature of this school subject has allowed for learning to become conceptualized knowledge for students and brings it into real-world uses. It, therefore, has much to offer to the STEM education reform efforts (Marginson et al., 2013; Ritz & Fan, 2015).

In Thailand, the government launched the two decades of Thailand Strategic Plan (2018 – 2037) that focuses on the digital economy called "Thailand 4.0," which needs to move forward in the 21st Century through prosperity, security, and sustainability. The dynamic economy, then, should be driven through innovations. To obtain the goal of Thailand 4.0, creative and holistic thinking is a critical feature of students' STEM learning and should be implemented in the citizen through education (Yuenyong, 2019). It seems that the national STEM Education Committee vigorously sets the driving mechanic because their committees include not only a key person from educational agencies but also a person from the national budget and planning. The STEM Education committee mainly focuses on four areas, including the development of STEM education in basic and higher education, STEM workforce development, planning and policy for STEM Education, and pilot program development for STEM Education and scale-up (Sutaphan and Yuenyong, 2019).

It is a good start for STEM education in the school setting to provide a STEM workforce and career. There were some pilot programs of Thailand STEM education that IPST, OBEC, OVEC, and OHEC mainly supported. The teacher development programs about STEM pedagogy were provided across the nation. Teaching and learning should be provided as integrated learning through activities based and project-based suggested by the IPST, the leading organization of STEM education driving in Thailand (IPST, 2012; Yuenyong, 2019). To enhance students to develop the projects based on their societal context, Yuenyong (2013) suggested that science learning activities should be provided through the science, technology, and society (STS) approach.

Another view of science, technology, and society (STS) is a teaching approach to enhancing students' practicing knowledge in the real world. The STS allows students to learn science through solving problems and scientific inquiry related to societal issues, technological issues, or products. The STS unit enhanced students to get ideas of linking their innovative ideas to entrepreneurship, which required applying the innovation to bring the ideas to life. (Yuenyong & Narjaikaew, 2009; Yuenyong, 2013; Yuenyong, 2017; Sutaphan & Yuenyong, 2019). In the UK, an example of introducing STS for STEM education, the ASE (2010) suggested the STS unit called SATIS (Science and Technology in Society) units in the UK STEM learning website assisting teachers in instructing from a STEM perspective. To provide STEM education pedagogy for professional teacher programs, Sutaphan & Yuenyong (2019) proposed the context-based STEM education teaching approach by adapting Yuenyong's (2006) STS teaching approach integrated with the engineering design process. They devised the seven stages of the STEM (Science, Technology, Engineering, and Mathematics) teaching approach. These include (1) identification of social issues, (2) identification of potential solution, (3) need for knowledge, (4) decision-making, (5) development of prototype or product, (6) test and evaluation of the solution, and (7) socialization and completion decision stage.

Some studies could provide STEM education learning activities regarding Sutaphan & Yuenyong's (2019) STEM education as inquiry from context. Those studies show somehow, problem in contexts requires technology and/or engineering (Mordeno et al., 2019; Villaruz et al., 2019; Ebal et al., 2019; Theerasan & Yuenyong, 2019). Discussion on the philosophy of technology and/or engineering may provide some more understanding of putting other knowledge into STEM integration. Sutaphan & Yuenyong (2019) argued that T-technology provided a strong link between science and society. Regarding the four modes of the philosophy of technology (de Vries, 2017), it suggested that students' learning in STEM education requires creative thinking skills. Creative thinking skill is crucial for designers to realize fitting between physical and functional nature and for users to seek ways to use technolog.

Works of literature about students' assessment in project-based learning (PjBL) which assess pupils' competencies by working on integrated projects, suggested that students' creative thinking skills should be considered (Barlex, 2002). The assessment can focus on students' creative thinking skills that could be viewed through the design process of their projects. Project-based learning has the potential to enable pupils to research, plan, design, and reflect on the creation of technological projects (Doppelt, 2009). Assessing creative thinking in PjBL could do as a part of teaching methods and learning environments such as portfolio assessment – a method based on records of students' activities. The portfolio manifests how they question, analyze, and solve problems, what students have learned as well as the new ideas throughout their learning. It also shows how students interact with others emotionally, intellectually, and socially (Collins, 1991; Wolf, 1989).

Furthermore, some studies assessing creative thinking in PBL/PjBL adopted De Bono's theoretical framework of creative thinking (Barak & Doppelt, 2000; Doppelt, 2009, 2005). Creative thinking was viewed as a synthesis between lateral and vertical thinking. There are two types of thinking, lateral thinking, and vertical thinking. Lateral thinking refers to discovering new ways of thinking for a wealth of ideas, while vertical thinking deals with developing ideas and checking them against objective criteria. The former is generative; it can move freely to generate a new way without specific correctness, not fixed classifications. The latter is sequential and selective; it moves only when there is a way to move and selects the most promising approach to a problem, while lateral thinking generates many alternative approaches (De Bono, 1996). According to De Bono, the processes of both types of thinking are beneficial. Lateral and vertical thinking synthesizes creative thinking, each complementing the other. Unlike creative thinking, curricula and research in the traditional approach address creativity, mathematical-logical thinking, and critical thinking as separate entities. Waks (1997) suggests that lateral thinking habits should replace conventional vertical thinking in education-for-all programs.

As a synthesis of lateral and vertical thinking, the perception of creative thinking, emphasizes the cognitive implications of technology education, particularly project-based learning. Various opportunities are provided by technology to promote imagination and a wealth of ideas and for the latest product development to fulfill human demands (Doppelt, 2009). Some studies by Barak & Doppelt (Barak & Doppelt, 2000; Doppelt, 2009, 2005) used the Creative Thinking Scale (CTS) to assess pupils' portfolios for creative thinking. It examines how pupils deal with complex problems and find solutions that depend on creativity to support the notion which is applied lateral and vertical thinking. Barak & Doppelt (2000) reported that the Creative Thinking Scale (CTS) was used to assess the suggested Creative Design Process (CDP). It comprises De Bono's (1996) four thinking, including awareness of thinking, observation of thinking, strategy, and reflection upon thinking.

Awareness of thinking is the first level that deals with developing awareness that thinking is a skill that can be developed. Students are taught how to prepare to engage in thinking about something, how to control inquiry, and how to listen to and assess other opinions. Observation of thinking is the second level deals with observing the consequences of action and choice, considering other people's views, and comparing alternatives. Thinking strategy is the third level that deals with the directed use of some thinking tools, organizing thinking as a sequence of steps, and using thinking to define the goal. Besides, reflection upon thinking is the fourth level that deals with the systematic use of thinking tools, a clear awareness of the need for reflective thinking, self-evaluation of thinking, designing thinking tasks, and methods to implement these tasks.

Water crisis and management is one issue that requires people who hold creative thinking to solve problems. To develop a STEM education as inquiry from context, the issue of water crisis provides some context for students to design/make something as a solution. Students may discuss how to solve problem related to the untreated water, lack of investment in infrastructure or technology to draw water from water resources, and how to make clean water. This study, therefore, aimed to enhance Grade 8 students' creative thinking in the water STEM education learning unit. Then, students could be enhanced to design their solution through the seven stages of teaching and learning on STEM education (Sutaphan and Yuenyong, 2019). The students' applying knowledge and creative thinking could be examined when they develop some STEM projects as the solutions of water issues. Creative thinking in this study have followed the de Bono (1970)' creative thinking. It is a synthesis of lateral thinking and vertical thinking, each complementing the other (De Bono, 1996). Besides, this study adapted Barak and Doppelt (2000)'s Creative Thinking Scale (CTS) to assess students' applying knowledge and creative thinking. In this study, the CTS was used to assess students' process of developing a solution for water crisis.

METHOD

Methodology regarded interpretive paradigm. Grade 8 students' tasks were be interpreted what and how students' applying knowledge to solving problem for the provided problems in the context. It also clarifies how the unit enhances students' creative thinking skills. The students' applying knowledge and creative thinking could be examined when they develop some STEM projects as the solutions of water issues.

Participants

Participants include 45 Grade 8 students who were studying in Khon Kaen University Demonstration school, Khon Kaen, Thailand.

Invention of the water STEM education learning unit

The water STEM education learning unit was provided for Grade 8 students. The intervention was developed and taught by the first author. The first author is a science teacher in Khon Kaen University Demonstration School (KKUDS). She has been taught in KKUDS for more than 20 years. The goals of this unit were not only to enhance understanding of student scientific concepts related to water for life but also gaining students' creative thinking and other skills related to the developing prototypes or products as solutions of social issues about water.

The learning activities were developed based on framework of teaching approach for STEM education as inquiry from context (Sutaphan and Yuenyong, 2019) which consists of 7 stages of teaching. These included (1) Identification of social issues, (2) Identification of potential solution, (3) Need for knowledge, (4) Decision-making, (5) Development of prototype or product, (6) Test and evaluation of the solution, and (7) Socialization and completion decision stage. Based on the 7 stages, the learning activities were provided into 6 lesson plans in three weeks (12 hours). However, the learning activities have been provided extra time for 4 hours mentioned in the lesson plan 3 and 6. The designing of lesson plans for the 7 stages was organized as showing in the Table 1. The learning activities of the unit were highlighted as the appendix.

Data collection

Students' tasks will be interpreted what and how students' applying knowledge to solving problem for the provided problems in the context. Besides, it also clarifies how the unit enhances students' creative thinking skills. The students' applying knowledge and creative thinking could be examined when they develop some STEM projects as the solutions of water issues. The portfolio assessment (Barak & Doppelt, 2000; Doppelt, 2005) will be used for examining students' applying knowledge and creative thinking when students learn the water STEM unit. The portfolio might consist of such items as written material, computer files, audio and video media, sketches, drawings, models, and pictures. The portfolio reflects what students have learned, how they question, analyze, synthesize, solve problems, and create new ideas, and how then design and build useful products or systems. The portfolio also shows how pupils interact intellectually, emotionally, and socially with others (Collins, 1991; Wolf, 1989). This study adapted Barak and Doppelt (2000)'s Creative Thinking Scale (CTS) to assess students' applying knowledge and creative thinking.

Table 1. The designing of lesson plans for the 7 stages of STEM pedagogy

Lesson plan stages of teaching	P1	P2	P3*	P4	P5	P6*
1. Identification of social issues						
2. Identification of potential solution,						
3. Need for knowledge						
4. Decision-making						
5. Development of prototype or product,						
6. Test and evaluation of the solution						
7. Socialization and completion decision						

* Extra time

Data analysis

This study adapted Barak and Doppelt (2000)'s Creative Thinking Scale (CTS) to assess students' applying knowledge and creative thinking. In this study, the CTS was used to assess students' creative when they design their solution through the seven stages of teaching and learning on STEM education (Sutaphan and Yuenyong, 2019). The CTS was developed an assessment scale of the creative thinking level achieved by students based on the elements they included in their portfolios. The creative thinking skills were clarified based on De Bono (1996)'s four achievement levels of creative thinking skills development. The four thinking levels included awareness of thinking, observation of thinking, thinking strategy, and reflection upon thinking.

The CTS evaluates the students' portfolios across two dimensions. The first considers the design, construction, and evaluation of the product or system. Evidence of lateral thinking, including originality, authenticity, usefulness, and unique design is sought. Likewise, evidence of vertical thinking is also sought and includes functionality, reliability, accuracy, geometric structure, and the application of scientific principles.

The second dimension considers the processes of learning and includes thinking, problem solving, and teamwork. Evidence is sought of individual and group efforts in problem solving, collaborative decision-making, and leadership. Table 2 presents the CTS, the development of which was detailed elsewhere (Barak & Doppelt, 2000).

FINDING AND DISCUSSION

Findings

According to learning activities in Table 2, students have chance to learn practicing scientific, mathematics, and other knowledge to design the things for solutions of water issues. The learning activities began with the situation of water pollution and ecosystem. The proposed issues suggested students to find the problems and consider about the answering. The Identification of potential solution asked students to develop ideas about the designing technology for water issues. Students had to list about existing related knowledge and need for knowledge of water, five capitals, and possible solutions. The identification of potential solution also engaged students to inquiry for scientific knowledge about water. Then, the need for knowledge stage, teacher provided learning activities for inquiring scientific knowledge about water.

Table 2. The Creative Thinking Scale (CTS)

Achievement Levels	Portfolio's Components	
	Design, construction, and evaluation of the system or product	Learning, thinking, and problem-solving activities
Level 1: Awareness The awareness to consider thinking as a skill which can be developed; prepare to think about something; prepare to inquire and to listen to other opinions.	Standard diagram of a system or product taken from available literature. Basic explanation of the model and its construction. Description of the model by means of pictures or sketches.	An example of solving a simple problem in planning and construction. Division of tasks among the team members. A few examples of using lateral and vertical thinking tools.
Level 2: Observation The observation of consequences of action and choice; consider the views of others; compare alternatives.	Original schematic diagram of system or product designed by the pupil. Detailed drawings of the model. Specification of planning and construction stages including calculations, specifications or computer programs.	Justified examples of choices among a number of alternatives. Information exchange and reciprocal help in the team. Various examples of using thinking tools.
Level 3: Strategy The directed use of some thinking tools; organizing the thinking as a sequence of steps; using thinking to define goals.	Original system functional block diagrams, structural tree or flow chart. Description of a number of iterations in the planning and construction of the model. Comparison among possible models and choosing from them.	Examples of the contribution of individuals and teamwork to solving problems. Evidence of the planned use of the thinking tools, open-mindedness, and postponing decision making (lateral thinking); setting priorities, goals and criteria (vertical thinking).
Level 4: Reflection A systematic use of thinking tools; clear awareness of reflective thinking; self-evaluation of thinking; designing thinking tasks and methods to implement these tasks.	Examination of the final product's features, compared to the set goals. Conclusions on successes or difficulties during the development process. Suggestions for improvement in the planning and construction process.	Conclusions drawn from the influence of the team's collaboration on the completion of the project. Students' view on the influence of the team's functioning on thinking and learning processes. Assessment of the selected solution compared to the goals.

These included experiment about state of water and methods of separating water, calculation of water percentage in student body, ways of water getting into body, water and moving minerals and vitamins into the cells, water as symbol of element, water cycle, studying about King Rama IX artificial rain, water in the world, field trip about water and ecosystem at the Srithan Lake, experiments about purifications, and reviewing simple fillers. After students learn some more knowledge about water, in the decision stage, they have to make decision about solutions of purifying water. They listed possible solutions and then selected a solution based their values and concerning on five capitals. In development of prototype or product, students developed some prototypes or products of filters. Students may apply scientific and other knowledge to develop ideas of filters' prototypes or products.

Scientific knowledge included water as solution, methods of separated substances, and the relationship between water, energy, living things, kinds, and forms of water. And other knowledge was considered; for example, capitals, values about needs of water, skills, techniques, and so on. Then, students shared the ideas about framework of test and evaluation of the water filters. Their water filters were evaluated through the aesthetic value/packaging/branding, taste, cost, quality of water, ideas of responsibility to solve environmental and social issues, and values about needs of water. Scientists, engineers, and marketing persons as panel of judges were invited to evaluate and reflect ideas on students' projects. Finally, the socialization and completion decision stage, students presented their projects in the annual school STEM festival where they have gotten reflection for revising prototypes and ideas about value of entrepreneurship.

The students' developing projects as solutions of water issues were assessed for their applying knowledge and creative thinking skills based on the CTS framework that is provided in Table 2. The portfolio elements at the end of the water STEM education unit revealed that most elements could be interpreted for achievement of creative thinking at the layer of awareness. Some of them could be viewed as the layer of observation, strategy, and reflection. Each group of students' layers of achievement of creative thinking is presented in the table (see the appendix).majority of students' developing a solution could be interpreted as creative thinking achievement at level of awareness, it seems that they did not familiar to this teaching approach in which students need to investigate related knowledge instead of following the textbook, and they also have to develop a prototype as a solution. They were exciting when they have chance to use mobile devices for searching information to develop ideas. However, many of them followed ideas from the literature from Internet. Students probably did not familiar to study in active learning STEM education because it was their first time. In the STEM education unit, they have to develop their creative thinking for designing solutions. Unlike the traditional class, students need to learn by following the textbook. Interestingly some groups of students could develop ideas of solutions that indicate creative thinking achievements at higher levels, namely observation, strategy, and reflection.

Discussion

Students' creative thinking achievement at the level of awareness

There were nine groups of students developing a solution that was assessed as creative thinking at the level of awareness. These included Waterfall, Aqua, Aphrodit, Natural resources, Somchai, Sand, Forrest, Mineral, and Soil group. A diagram of their designed products can be shown in the appendix as Figure 1to Figure 9.

These groups of students designed and presented standard diagrams of water filter products that were taken from the available literature. Description of the water filter models was presented by means of pictures or sketches. They designed to use the bottle as a filter container. Besides, use different sizes of material gains to be added as various kinds of filters. There are few explanations for the synthesis of lateral and vertical thinking tools. However, they showed their lateral thinking when they drew the layers of filters but did not clarify their justifications about those layers.

As each group of students provided a different design of layered filters. The filters were materials that provide different channels for water flowing through. The sizes of material gains, therefore, were considered as criteria for the selected kinds of filters. For the Waterfall group, they designed top-down layers of filters, including fine sand, coarse sand, charcoal, fine sand, and coarse gravel, respectively. For the Aqua group, they designed top-down layers of filters to provide drinkable water. These layers included fine gravel, sand, powder charcoal, cotton wool, and cloth, respectively. For the Aphrodit group, they designed top-down layers of filters comprising fine sand, coarse sand, charcoal, peanut, fine gravel, coarse gravel, and cotton wool, respectively. For the Natural resources and Mineral group, they designed top-down layers of filters, including fine sand, coarse sand, charcoal, fine sand, coarse gravel, and cotton wool, respectively. The Somchai group designed top-down layers of filters, including fine gravel, fine sand, powder charcoal, and cloth, respectively. For the Sand and Forrest group, they designed the top-down layer of filters, including fine sand, coarse sand, charcoal, fine gravel, coarse gravel, and cotton wool, respectively. The last group, Soil, designed top-down layer sof filter, including fine sand, coarse sand, powder charcoal, cotton wool, and cloth, respectively.

Students' creative thinking achievement at the level of observation

Two groups of students' portfolio elements for designing a solution could be interpreted as creative thinking achievement at the level of observation. These included Namsai and the O2 motor groups.

Namsai group designed the products for purifying water concerning water flowing through filters and water heating as shown in the appendix, Figure 10. They identified their problem as purifying contaminated water and crafted filters that probably learned from the literature by adding some more ideas of purifying water. This could be viewed that they could design original schematic diagram of product. Detailed drawings of the model provided the heating of water after flowing water through filters. They designed the top-down layer of filters, including gravel, sand, charcoal, and cotton wool. Then, the water will be heated to separate some contaminated compounds. Moreover, these students could provide the specification for constructing the filters and water heater, yet they did not clearly mention how to test the quality of drinking water.

The O2 motor group of students designed the products of purifying water by adding oxygen into the water designed in diagram as shown in the appendix (Figure 11). They provided the original schematic diagram of the designed product. Detailed drawing of the model shown both the top and side views. Their presentation could prove that they are concerned about the energy put in by batteries. They search for information about the appropriate battery power and kinds of turbines to fit the size of the O2 motor machine. Learning, thinking, and problem-solving activities of their group were revealed when they presented the idea of how the turbine to put in Oxygen was reviewed from the King Rama IX Chaipattana project.

Students' creative thinking achievement at the level of strategy

This study also found that three groups of students' portfolio elements for designing a solution could be interpreted as creative thinking achievement at the level of strategy. These include Namkangsai, Energy of Water, and Phuwataan groups.

The first group, Namkangsai, design a product as shown in the appendix, Figure 12. It could be assessed as creative thinking achievement at the level of strategy. This could be viewed when their synthesis of lateral thinking and vertical thinking for 1) design, construction, and evaluation of product; and 2) learning, thinking, and problem-solving activities were interpreted.

The group consisted of eight students designing a convenient device for cleaning water. They could organize their thinking as a sequence of steps and use thinking to define their goal. The jug was modified to be a device. Then, they explain the design of jug water filter. These include (1) three different sizes of materials gains were put into a jug, (2) the water in a jug was put as the hole indicated as number 1, (3) water moves through different layers down to the bottom of the jug, and (4) water could move out from the hole number 2. Then, they clarified the goals of this device, including (1) they could provide drinkable water, (2) their design could provide the idea of DIY water filter that everyone could do by themself, (3) materials for developing a device were used materials, and (4) the product is a natural filter. Their goal might represent that they performed vertical thinking.

According to Namkangsai's ideas, it seemed that they provided an original system functional block diagram. They described steps in the planning and construction of the model and also compared it to other possible models, and then they chose this idea because it could provide DIY ideas, use cast-off materials, and produce natural products. This represents their lateral thinking. However, they did not clarify their justifications about layers filters which may represent what knowledge could be applied and never explained how to evaluate quality of water in level of drinkable.

The second group, Phuwataan, designed a solution as shown in the appendix, Figure 13. It could be assessed as creative thinking achievement at level of strategy. This could be viewed when their synthesis of lateral thinking and vertical thinking for 1) design, construction, and evaluation of product; and 2) learning, thinking, and problem-solving activities were interpreted.

Phuwataan students were interested in engineering when developing ideas of possible solutions which are related to motor, energy, light, battery, engines, and electrical device. Then, the teacher asked them to study further what an engineer is. The students designed a machine of killing bacteria in water. They could organize their thinking as a sequence of steps and using thinking to define their goal. They clarified that water may contain bacteria, and that they developed the possible ways to kill the bacteria in water. The properties of lens will be used to provide light intensity enough to kill the bacteria in water.

According to Phuwataan students' ideas, it seemed that they provided an original system functional block diagram. They described steps in in the planning and construction of the model. They also compared to other possible models, then, they chose this idea because it could find the lens and sun light. However, they need to think about the size of the lens for providing appropriate light intensive to kill bacteria.

The last group, Energy of Water, designed a solution as shown in the appendix, Figure 14. It could be assessed as creative thinking achievement at the level of strategy. This could be viewed when their syntheses of lateral thinking and vertical thinking for 1) design, construction, and evaluation of product; and 2) learning, thinking, and problem-solving activities were interpreted.

Energy of Water group designed a lamp using energy from water. They set their goal as using water for green energy. They could organize their thinking as a sequence of steps and using thinking to define their goal. They probably searched information related to their ideas and then tried to develop their own designed diagram. It seemed that their ideas adapted from WAT or WAT (er) of Manon Leblanc, a water-powered lamp. A few drops of water combine with a battery hydroelectric (composed of a stick of carbon coated with magnesium powder) and give rise to a process that generates an electro chemical reaction and creates energy. The water then generates an electro chemical reaction that generates light. Based on this literature, it seemed that they provided an original system of functional block diagram. They also described steps in in the planning and construction of the model.

CONCLUSION

The present study indicates that the water STEM education learning unit situated students to develop their creative thinking for developing projects as solutions for water issues. It was found that most students held creative thinking achievement at the level of awareness when they were developing the water purifying projects. It seems that these learners did not familiar with this teaching approach which required them to investigate related knowledge instead of following the textbook, and they also had to develop a product as a solution. They were excited when they have chance to use mobile devices for searching information to develop ideas, but many of them followed ideas from the literature on the Internet. Even though most students held creative thinking achievement at the level of awareness, some other groups of students having creative thinking achievement at the level of strategy. It could be viewed that the seven stages of teaching approach for STEM education as inquiry from context (Sutaphan and Yuenyong, 2019) scaffold students to practice knowledge to design something as solutions based on their creative thinking.

This implementation suggests some lessons learned from STEM education teaching. These include enhancing the students' 21st century learning skills, active learning, and capability for developing possible solutions. To prepare STEM education teaching, teachers also need to be strong in scientific concept and other related knowledge because the STEM education learning activity asked students to design something that required related knowledge and skills (Chachashvili-Bolotin et al., 2016; Coppola et al., 2015; Ejiwale, 2013; Hasanah & Tsutaoka, 2019; Nadelson & Seifert, 2017). For example, for the water STEM unit, the teacher needs to know the water in term of physics, biology, and chemistry. The literatures of engineering design about water also need to be reviewed by the teacher. In this context, water energy lamp suggested the teacher to review more about the designs of various water energy lamps.

This study suggested also that students need to demonstrate their creativity and innovation skills in designing the visual of their prototype. Creative thinking, both lateral thinking (originality, authenticity, usefulness, and unique design) and vertical thinking (application of scientific principles) should be situated in STEM education learning activities. The teaching approach should likewise consider the processes of learning and include thinking, problem solving, and teamwork. Evidence is sought of individual and group efforts in problem solving, collaboration, decision-making, and leadership.

In STEM education as inquiry from context needs, teachers need to facilitate students to find their appropriate solution based on the context. Teachers have to enhance students' skill to design and share ideas among groups to seek solutions for the social's problems (Shadle et al., 2017; Shernoff et al., 2017). STEM education learning activities, therefore, should give students opportunities to communicate ideas for designs. At the end, students can have appropriate competence to share ideas and projects reflecting their responsibility to solve environmental and social issues (Sutaphan and Yuenyong, 2019).

REFERENCES

Association for Science Education (ASE) (2010). *STEM resources – SATIS revisited*. Retrieved from: https://www.stem.org.uk/resources/collection/2885/satis-revisited.

Barak, M., & Doppelt, Y. (2000). Using portfolios to enhance creative thinking. *Journal of Technology Studies*, *26*(2), 16–24.

Barlex, D. (2009). The STEM programme in England—Help or hindrance for design and technology education? *Paper presented at the PATT22 conference*, Delft, Netherlands. Retrieved from http://www.iteaconnect.org/Conference/PATT/PATT22/Barlex.pdf.

Bell, D. (2012). Perceptions of STEM, within the context of teaching D&T in secondary schools: A phenomenographically inspired study. In T. Ginner, J. Hallstro¨m, & M. Hulte´n (Eds.), *Technology education in the 21st century* (pp. 74–79). Linko¨ping: Linko¨ping Electronic Conference Proceedings.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. Arlington: NSTA Press.

Barlex, D. (2002). The relationship between science and design and technology in the secondary school curriculum in England. In: I. Mottier, & M. J. de Vries (Eds.), *Proceedings of the PATT12 Conference*, 3–12.

Chachashvili-Bolotin, S., Milner-Bolotin, M., & Lissitsa, S. (2016). Examination of factors predicting secondary students` interest in tertiary STEM education. *International Journal of Science Education*, 38(3), 366-390.

Coppola, S. M., Madariaga, L. A., & Schnedeker, M. H. (2015). Assessing teachers' experiences with STEM and perceived barriers to teaching engineering. In *Proceedings from Annual American Society of Engineering Education Conference and Exhibition*.

Collins, A. (1991). Portfolio for biology teacher assessment. *Journal of School Personnel Evaluation in Education*, *5*, 147–167.

De Bono, E. (1996). *Master workshop of de Bono's thinking course*. Jerusalem: Branco Weiss Institute for the Development of Thinking

DeCoito, I (2016). STEM education in Canada: A Knowledge synthesis. *Canadian Journal of Science, Mathematics and Technology Education*, 16 (2): 114 – 128.

DeCoito, I., & Richardson, T. (2016). Focusing on integrated STEM concepts in a digital game. In M. Urban & D. Falvo, (Eds.), *Improving K-12 STEM education through technological integration* (pp. 1-23). Hershey, PA: IGI Global.

de Vries, M.C. (2007) *Relations between science education and technology education: what can we learn from the philosophy of technology?* Document for lecturing at Science Education program, Khon Kaen University, during 14 - 15 September 2007.

Doppelt, Y. (2005). Assessment of project-based learning in a MECHATRONICS context. *Journal of Technology Education*, 16(2), 7–21.

Doppelt, Y. (2009). Assessing creative thinking in design-based learning. The *International Journal of Technology and Design Education*, 19:55–65

Ebal Jr, CD, Luga, MJF, Flores, MRO, Zabala, DJP, Buan, AT, & Yuenyong , C (2019). Linear equations in two variables STEM education learning activities: Developing the household power consumption calculator app. *Journal of Physics: Conference Series*, *1340*(1), 012048.

Ejiwale, J. A. (2013). Barriers to successful implementation of STEM education. *Journal of Education and Learning*, 7(2), 63-74.

Hasanah, U., and Tsutaoka, T. (2019). An outline of worldwide barriers in science, technology, engineering and mathematics (STEM) Education. *Jurnal Pendidikan IPA Indonesia*, 8(2): 193 – 200.

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. *Journal of STEM Teacher Education*, 48(1), 96–122.

Institute for promoting science and technology teaching (IPST). (2012). *Technological Process*. Retrieved from www.designtechnology.ipst.ac.th/index.php/?option=com _content&view= article&id=69&Itemid=108.

Kim, J. S. (2011, November). New national curriculum of technology education in Korea. *Paper presented at the 2011 international conference on technology education in the Pacific-Rim Countries*, Nagoya, Japan.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparison.* Melbourne: Australian Council of Learned Academies.

Mordeno, I. C., Sabac, A. M., Roullo, A. J., Bendong, H. D., Buan, A., & Yuenyong, C. (2019). Developing the garbage problem in Iligan city STEM education lesson through team teaching. *Journal of Physics: Conference Series*, *1340*(1), 012046.

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, *110*(3), 221-223.

Ritz, J. M., & Fan, S. C. (2015). STEM and technology education: International state-of-the-art. *Int J Technol Des Educ*, *25*, 429–451.

Sanders, M. (2009). STEM, STEM education STEMmania. *The Technology Teacher*, *68*(4), 20–26.

Shadle, S. E., Marker, A., & Earl, B. (2017). Faculty drivers and barriers: Laying the groundwork for undergraduate STEM education reform in academic departments. *International Journal of STEM Education*, *8*(4), 1-13.

Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing educator education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, *13*(4), 1-16.

Sutaphan, S. Yuenyong, C. (2019). STEM Education Teaching approach: Inquiry from the context based. *Journal of Physics: Conference Series*, *1340*(1), 012003.

Theerasan, C. & Yuenyong, C. (2019). Developing the floating restaurant STEM education learning activities for Thai secondary school students. *AIP Conference Proceedings*. 2081, 030023-1– 030023-6. (View online: https://doi.org/10.1063/1.5094021).

Villaruz, E. J., Cardona, M. C. F., Buan, A. T., Barquilla, M. B., & Yuenyong, C. (2019). Ice cream STEM education learning activity: Inquiry from the context. *Journal of Physics: Conference Series*, *1340*(1), 012092.

Williams, P. J. (2011). STEM education: Proceed with caution. *Design and Technology Education*, *16*(1), 26–35.

Wolf, D. (1989). Portfolio assessment: Sampling student's work. *Educational Leadership*, *45*(4), 35–39.

Yuenyong, C. (2006). *Teaching and learning about energy: Using STS approach*. Bangkok, Thailand: Thesis of Doctoral Degree in Science Education, Kasetsat University.

Yuenyong, C. (2013). Enhancing Scientific Literacy in Thailand. *Global Studies of Childhood*, *3*(1), 86 – 98.

Yuenyong, C. (2017). Enhancing Thai students' thinking skills about energy issues: Influence of local values. *Chemistry: Bulgarian Journal of Science Education*, *26* (3), 363 – 376

Yuenyong, C. (2019). Lesson learned of building up community of practice for STEM education in Thailand. *AIP Conference Proceedings*. 2081, 020002-1 – 020002-6.

Yuenyong, C. and Narjaikaew, P. (2009) Scientific literacy and Thailand science education, *International Journal of Environmental and Science Education*, *4*(3), 335-349.

APPENDICES

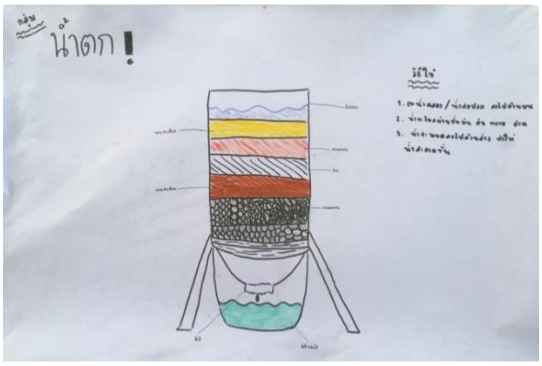

Figure 1. Water fall group diagram

Figure 2. Aqua group diagram

Figure 3. Aphrodit group diagram

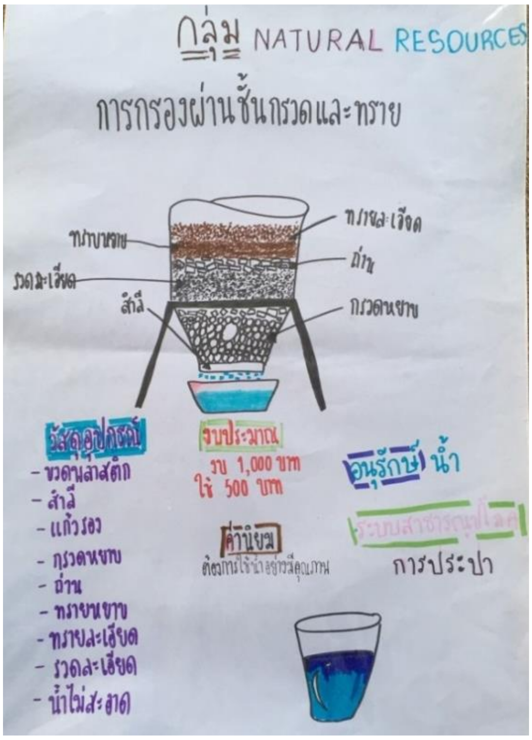

Figure 4. Natural resources group diagram

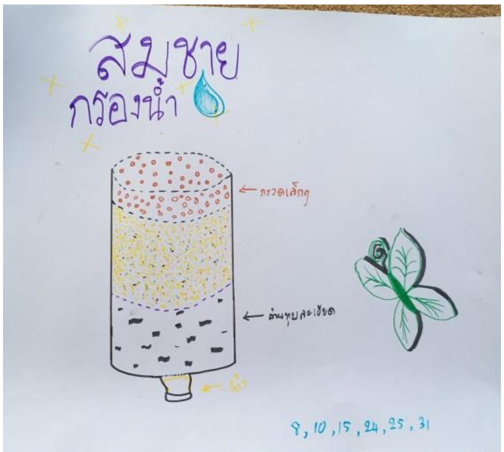

Figure 5. Somchai group diagram

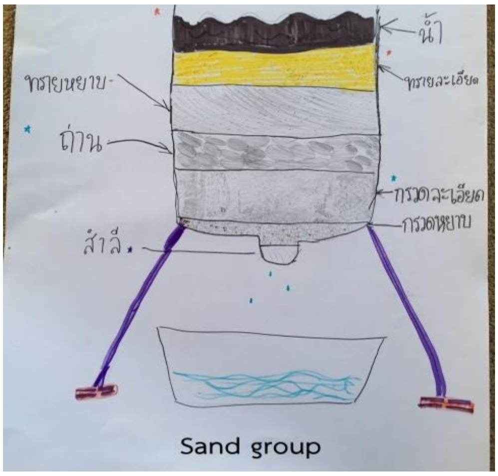

Figure 6. Sand group diagram


Figure 7. Forrest group diagram

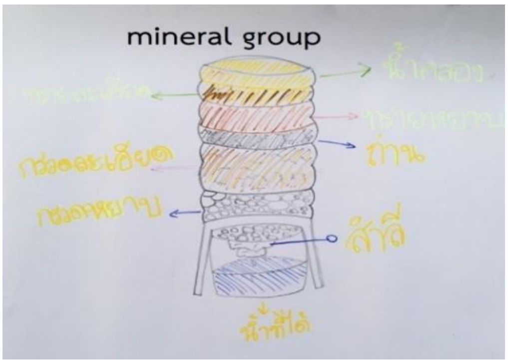

Figure 8. Mineral group diagram

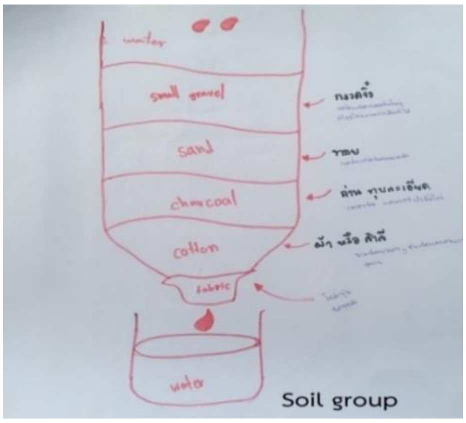

Figure 9. Soil group diagram

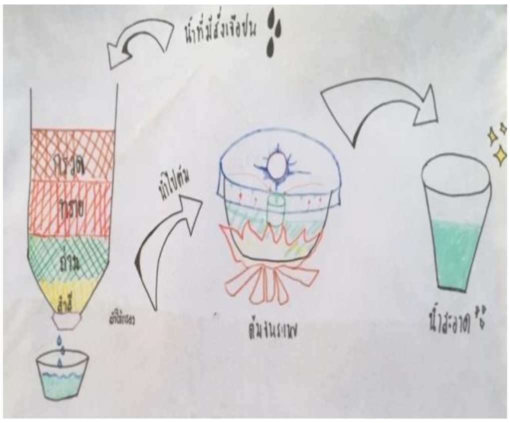
Figure 10. Namsai group diagram

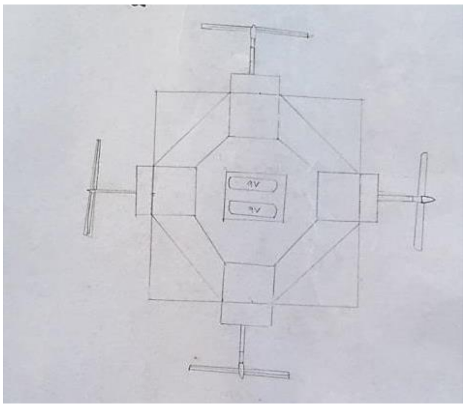
Figure 11. O2 Motor group diagram


Figure 12. Namkangsai group diagram

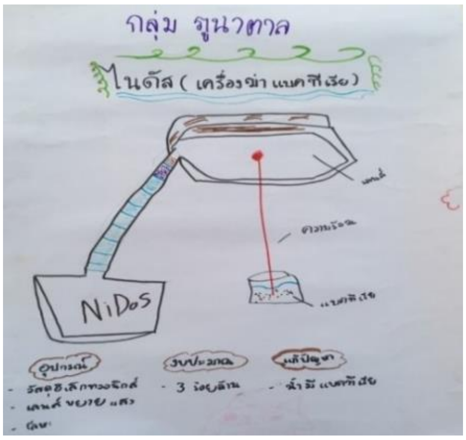

Figure 13. Phuwataan group diagram

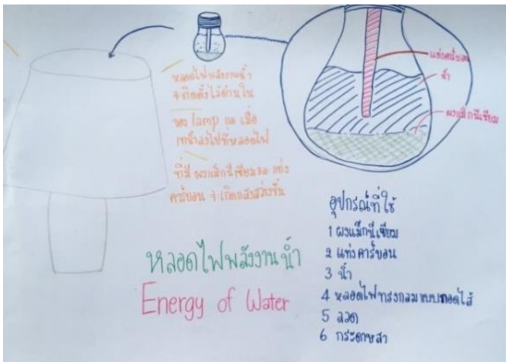

Figure 14. Energy of water group diagram

Table 2. Highlight of the water STEM education learning unit

Stages of teaching	Lesson plan	Learning activities
1. Identification of social issues	P1	The issues of water crisis were brought to the class. Students discuss and complete the worksheets for the following issues. - Is the world in a water crisis? Students discuss about the global population and living under conditions of severe water scarcity. - What countries are affected by the water crisis? Students read the sheet about five countries with the greatest water scarcity issues. These included Yemen, Libya, Jordan, the western Sahara, and Djibouti. - And how about our country, Thailand? and also, how about your community like, your province, your school, your home. - The video clip of water pollution ad ecosystem in Khon Kaen city was provided for Grade 8 students. - Students find further information about water pollution and ecosystem.
2. Identification of potential solution	P1	Students discuss and complete the worksheets for the following issues. - What can cause water pollution? Students may discuss about human sewage or cattle excrement that is untreated also causes water pollution in the same way as fertilizers do. - Problem of water crisis. The water scarcity problem is one of the most serious risks facing the world at every level: social, economic, political and environmental. - What are causes of water crisis? Students may search information and discussion about economic water scarcity is caused by a lack of investment in infrastructure or technology to draw water from water sources to satisfy the demand for water. - What is in dirty water? Students may discuss about contaminated water which could cause many types of diarrheal diseases. - How to make clean water? Students need to list the possible solutions as much as they can. - Students do brainstorming to design their thinking. They were asked to think about five capitals for their solutions. Physical capital refers to materials or infrastructure related to the issues.
2. Identification of potential solution	P1	Financial capitals, students need to think about budgets based on their contexts. Social capital, students consider about partnership which may support them for making clean water. Human capital, students may reflect what their prior knowledge and what required knowledge. Natural capital, students may concern about ecosystem in their local areas.
3. Need for knowledge	P3 (Extra time)	- Students study ecosystem field trip at the Srithan lake. - Write the report to explain water habitats at Srithan lake
4. Need for knowledge	P4	- Do experiments about purifications where need the different methods and skills of purifying. These, for examples, include water and liquid of salt, water and dust, water and oil, and so on. - Review simple fillers. Students may review about, for examples, stainless steel water distiller, megahome water distiller, pure water mini-classic CT countertop water distiller, H2O labs model-200 countertop home water distiller, CO-Z 4-liter pure water distiller set, CNC shop water distiller water distillation purifier

5. Decision-making	P4	Students will list possible solutions for what and how to make clean water. - Categorize the materials that could be provided in the filters. - Select a possible solution regarding their concerning on five capitals.
6. Development of prototype or product	P5	Students design technology for water filter. They may develop some prototypes or products of filters. Students may apply related knowledge to develop ideas of filters' prototypes or products. Scientific knowledge may include water as solution, methods of separated substances, and the relationship between water, energy, living things, kinds and forms of water. And other knowledge may be considered; for example, capitals, values about needs of water, skills, techniques, etc.
7. Test and evaluation of the solution	P5	A water filter will commence and there will be scientists, engineers, and marketing person panel of judges to be invited. Their water filters will be evaluated through the aesthetic value/packaging/branding, taste, cost, quality of water, ideas of responsibility to solve environmental and social issues, and values about needs of water. An open forum will commence so that the students will use this information to better improve their product.
8. Socialization and completion decision stage	P6	Each group will make a STEM project poster on their final product and present it in the annual school STEM festival. They can also display their output in the school and sell it. In this way, they will also learn the value of entrepreneurship.

Assessment of Portfolio elements for developing a solution of water issues through the Creative Thinking Scale (CTS)

Rank on CTS	Name Group of Portfolio Element	Interpretation
1	Waterfall	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, charcoal, fine sand, and coarse gravel; respectively.
	Aqua	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine gravel, sand, powder charcoal, cotton wool, and cloth; respectively.
	Aphrodit	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, charcoal, peanut, fine gravel, coarse gravel, and cotton wool; respectively.
	Natural resources	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, charcoal, fine sand, coarse gravel, and cotton wool; respectively.
	Somchai	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, charcoal, fine sand, coarse gravel, and cotton wool; respectively.

	Sand	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine gravel, fine sand, powder charcoal, and cloth; respectively.
	Forrest	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, charcoal, fine gravel, coarse gravel, and cotton wool; respectively.
	Mineral	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, charcoal, fine sand, coarse gravel, and cotton wool; respectively.
	Soil	Present standard diagram of water filter products that were taken from available literature. They showed their lateral thinking when they drew the layer of filters. Show different sizes of material gains to be added as various kinds of filters. These included fine sand, coarse sand, powder charcoal, cotton wool, and cloth; respectively.
2	Namsai	They provided the designing of filters that probably learned from the literature with adding some more ideas of purifying water. Detailed drawings of model provided the heating of water after flowing water through filters
	O2 motor	They provided the original schematic diagram of designed product. Detailed drawing of the model showed both top and side view. Learning, thinking, and problem-solving activities of their group were revealed when they presented that the idea of how the turbine to put in Oxygen was reviewed from the King Rama IX Chaipattana project.
3	Namkangsai	They designed a convenience device of cleaning water. They could organize their thinking as a sequence of steps and using thinking to define their goal. It seemed that they provided an original system functional block diagram. They described steps in in the planning and construction of the model. They also compared to other possible models, then, they chose this idea because it could provide DIY ideas, reuse materials, and natural products.
	Energy of Water	They designed a lamp using energy from water. They set their goal as using water for green energy. It seemed that their ideas adapted from WAT or WAT(er) of Manon Leblanc. Based on this literature, it seemed that they provided an original system functional block diagram. They described steps in in the planning and construction of the model.
	Phuwataan	They designed a machine of killing bacteria in water. They developed the possible ways to kill the bacteria in water. It seemed that they provided an original system functional block diagram. The properties of lens will be used to provide light intensity enough to kill the bacteria in water. They also compared to other possible models, then, they chose this idea because it could find the lens and sun light.