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Harnessing Project-Based Learning to Enhance STEM Students' Critical Thinking Skills Using Water Treatment Activity

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Abstract: Water treatment processes are designed to ensure that any pollutant's adverse effects on the environment are reduced to the minimum allowable discharge limit. Water-literate individuals ought to effectively and constantly think about novel hydrologic concepts to improve the quality and sufficiency of water. Socio-hydrological issues remain the main source of water pollution and insufficiency in society. Therefore, effective water management and treatment require societal understanding. The complexity of water issues requires equipping STEM education students with the necessary knowledge to acquire water solution reasoning skills. However, STEM students need meaningful challenges with everyday connections to capture their interest to apply intuitive understanding in project-based learning. Water-related issues such as high turbidity are ubiquitous problems facing communities. This study specifically explored how project-based learning can be harnessed to enhance STEM students' critical thinking skills using water treatment activities. The water treatment activity involved the development of novel products using agricultural wastes for efficient water treatment. The social issues associated with agricultural wastes, especially orange and banana peels in the environment, are too obvious to be overlooked; hence, they were chosen as base materials to develop water treatment products. The study adopted an action research design and involved 12 purposively selected third-year Bachelor of Science students majoring in Chemistry at a South African university. The students were divided into two groups consisting of six participants. The researchers implemented team teaching and invoked students' knowledge of Earth Science, Physics, Chemistry, and Technology to develop and implement laboratory experimental activities and class-based lesson plans. The empirical investigation was underpinned by the Five Steps of Project-Based Learning as the underlying theoretical framework. The chemistry of the processed peels such as particle size and functional groups provided insight into the mechanism responsible for water turbidity reduction. Laboratory experimental results revealed that the turbidity reduction obtained from the use of processed banana peels was higher than the processed orange peels coagulant. However, the performance of both coagulants in turbidity reduction complied with the South African National Standard (SANS241) for drinking water quality.

Keywords: agricultural wastes; coagulant; critical thinking; STEM; turbidity; water treatment

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1. Introduction

The increase in urbanization, anthropogenic activities, and rapidly expanding human population influence water-related challenges in developing countries. Industries and urban settlements produce nutrient concentrate, sewage effluent, and toxic pollutants, which could affect the water quality and lead to insufficient natural resources [1]. Thus, water pollution is a global concern and citizens need to be equipped with the knowledge and critical skills necessary to make science-based decisions through science, technology, engineering, and mathematics (STEM) education, which historically foregrounded the teaching and learning of disciplinary concepts [2]. However, one of the critical current issues in STEM education is students' inability to embrace self-directed learning. The desire to read for good grades remains a major learning goal for students while neglecting the

main purpose of education by failing to acquire the necessary skills and knowledge in their various fields [3]. Therefore, there is a need to equip STEM students with project-based learning skills to enable them to indulge in critical thinking.

While experimental aspects of science and technology in water treatment have been established, exposing this knowledge to citizens through STEM education is still pending [4]. For example, the United States of America has invested hundreds of millions of dollars to increase the rigor, relevance, and content of STEM education for K-12 students [5] to assert its position as a world leader in key areas such as economy, science, innovation, and technology [6,7]. Likewise, South African STEM education battles to develop STEM students with the relevant knowledge and skills to apply what they learn in solving authentic problems. The knowledge acquired remains unlocked when it comes to applicability in real life. Hence, there is a need to explore how project-based learning can be harnessed to enhance STEM students' critical thinking skills using inquiry-based activities such as water treatment activities. The emergence of integrated STEM education in some institutions suggests that this approach makes students better problem solvers and logical thinkers. Therefore, the current research focused on teaching strategies that facilitate the implementation of integrated STEM education in water treatment processes. The role of STEM education has evolved from providing students with STEM content knowledge and understanding to promoting students' interest in both learning and critical thinking through project-based learning. However, there is a paucity of empirical investigations on the effectiveness of innovative approaches to STEM education for university science students on water treatment product synthesis and application [8].

Water turbidity is an optical quality of water that gives the appearance of 'cloudiness' which masks the presence of bacteria, algae, and parasites that are harmful to humans. According to the United States Environmental Protection Agency (EPA), water with suspended particles of less than 10 µm poses great health problems because these particles could penetrate deep into the lungs or bloodstream [9]. Therefore, the World Health Organization (WHO) recommends that turbidity should not exceed 1 Nephelometric Turbidity Unit (NTU) before chlorination [10]. Efficient reduction of turbidity up to and below the allowable limit is required before water can be certified fit for consumption. It has been found that several chemically synthesized coagulants used to effectively reduce turbidity may also pose problems to the treated water because of hazardous chemicals from the coagulant during the water treatment procedure [11]. It is, therefore, necessary to explore coagulants involving eco-friendly and cost-effective biomass. In this study, fibrous agricultural wastes such as banana and orange peels were chosen as model base materials to develop novel water treatment products through project-based learning [12,13].

1.1. Project-Based Learning

Projects can be defined as intensive experiences that engage students in interesting activities that are important to the courses of study [14]. Some projects involve community members and often result in an exhibition or product for a real-world purpose or audience. Project ideas can be developed by teachers or students, either individually or in teams through critical thinking. Furthermore, experiences outside the school environment allow students to learn about their communities and their problems, which prompts them to brainstorm for possible solutions or features that could solve the problems and also make the project unique. The term project-based learning subsumes different activities with varying purposes which encourages practitioners and curriculum developers to reflect upon the purpose and possibilities of project-based learning along with the students by setting realistic and clear goals [15]. Practitioners and researchers are urged to design courses even more carefully, especially practical or experimental courses. The classroom management techniques used by teachers need to expose their expertise in the use of project-based learning instructional strategies. There are six desirable features of project-based learning which include authenticity of the problem and intended product, academic rigor, applied learning that is grounded in the context of life and work beyond school

walls, active exploration by students, adult connections that make adults and their work more visible to students, and assessment practices that include the use of clear criteria and structured self-assessment [14,16].

Project-based learning (PBL) improves students' ability to embrace self-directed learning [3,17]. While students are exposed to the theoretical aspects of learning to pass their grades, the practical application of knowledge in the real world remains a serious concern. Therefore, there is a need to equip students with project-based knowledge and critical skills necessary to provide sustainable science-based solutions. Several terms or approaches have been proposed by educational researchers to characterize learning and learning methods that focus on students' sensemaking such as "learning for understanding," "intellectually ambitious learning," and "authentic pedagogy. The PBL approach has been identified as one of the effective ways to engage students in learning as well as to incorporate literature on the project method for educational purposes [18]. Students may conduct projects independently and in teams or groups. At the high school level, projects can also be conducted with a whole class working with one or more other classes within the same school or working with one or more other classes from another school. Students can also be introduced to bigger projects meant for adults or researchers to unlock their creative potential and capabilities in critical thinking. Furthermore, adult projects offer rich opportunities for helping students to make interdisciplinary connections, address academic standards and goals, discover personal talents and interests, develop social skills, and use technology [19]. Therefore, PBL helps students to connect personal interests with the course content as they explore a theme in greater depth.

1.2. Development of Critical Thinking Skills in STEM Education

The lack of a good educational platform to develop important skills worldwide, especially in South Africa, makes it tedious to cultivate desired human resources who can comprehend efficient solutions to water problems. For example, the National Science Foundation (NSF) estimated that almost 20% of all jobs in the United States of America need STEM knowledge and skills [20]. In developing countries such as South Africa, a solid STEM grounding is needed in the education systems in order to cope with the continued changes in technology and economic development needs. STEM education is impactful in the scientific process and the development of students' investigation skills and critical thinking skills. Critical thinking skills encapsulate creativity, innovation, scientific literacy, and problem-solving skills [20,21]. Educators have realized that critical thinking skills are essential in education today mainly to deal with problems in an increasingly complex real-life situation. This awareness has triggered various studies focusing on critical thinking skills [22]. The reality is that the level of students' critical thinking skills determines their knowledge in the fast-growing fourth industrial revolution (4IR) era. Therefore, the development of students' critical thinking in STEM education is of vital significance in order to develop the intellectual capacity to grapple with fundamental science-based challenges that bedevil societies such as clean water scarcity.

Critical thinking is an essential capacity to influence directly the problem-solving process because this ability can aid students to decide the best alternative solutions. Moreover, critical thinking, statistics, computing, and the ability to understand how the world works are among the important factors needed in PBL. Therefore, PBL provides space for students to choose activities or solutions through critical thinking. It also presents great opportunities for teachers to implement and observe activities aimed at developing students' abilities. In other words, an integrated project-based STEM learning model can improve students' critical thinking skills [23,24] more than conventional learning [25].

1.3. Theoretical Framework

Project-based learning has been advocated as an effective means for promoting purposeful learning. It is an excellent instructional approach for combining language and content-learning aims, and improving students' literacy and research skills [26]. It is important to note that every project is the result of a series of activities conducted by the students or researchers. These activities are organized into stages. Generally, a project begins in the classroom/laboratory, moving out into the world, and returning back to the classroom. Most projects include the following steps: project presentation and identification, individual/team research planning, design development, building/testing/evaluation, and project delivery or product-making [27].

The project presentation/identification is often performed by educators by introducing the topic or problems to the students and also giving them an opportunity to express their opinions or to ask questions. Water problem issues in South Africa were presented to the students by the researchers, and all the students were afforded opportunities to share their ideas. The problem related to the disposal of agricultural wastes was also identified. The students worked on the project in groups while the researchers implemented team teaching. The researchers and students determined the mode for collecting agricultural wastes and surface water for use in the project. The students used critical thinking to discover the water treatment techniques and the route for coagulant preparation using orange and banana peels. The analytical techniques used were suggested by the researchers and other activities were assigned to the participants since it was team research [27,28].

The research building, testing, and evaluation steps are very important as these are the stages in which the main project work is done. Students were divided into groups A and B and gathered information from different sources. Project delivery or product-making is one of the main activities in research. Therefore, the information and material preparation on banana peels were done by group A while group B worked on orange peels. The two groups used a similar synthesis route for coagulants development and the performance of their synthesized wastes-based coagulants was evaluated in turbid water using a jar test experiment. The water samples before and after the treatment were analysed using Inductively Coupled Optical Emission Spectrometry (ICP-OES). The presentation of the students' final product to the whole class represented product delivery and the researchers provided feedback on the students' efforts. The concluding stage was the final step where the students drew conclusions based on their analysis of collected data [29].

1.4. Purpose of the Study

The study explored how project-based learning can be harnessed as a means to enhance STEM students' critical thinking skills using inquiry-based activities such as water treatment activities. This empirical investigation involved the implementation of PBL activities in STEM education settings to examine the impact of inquiry-based instructional practices on STEM learning involving water treatment as a key concept. This study, therefore, introduced project-based learning to develop students' conceptual understanding of water treatment processes and other related STEM concepts. The researchers invoked students' knowledge of Earth Science, Physics, Chemistry, and Mathematics to clearly articulate the steps involved in the design solution to water problems and the implementation of the outcome in real industrial applications. An experiential-based approach to STEM education in water treatment was adopted as part of the action research design using processed banana and orange peels as a model water treatment product for turbidity reduction. In addition, mathematical knowledge was applied to analyze the data obtained from the laboratory experimental activity.

1.5. Research Design and Methodology

The study adopted an action research design and involved the development of lessons on water treatment products and processes [30,31] The researchers implemented team teaching and invoked students' knowledge of different STEM subjects to develop and

implement both experimental activity and class-based lesson plans [32]. As part of team teaching, the researchers presented the sequence of processes that can be used to clean wastewater and facilitated a discussion on different particle sizes with their effects on water treatment. The technology used to design a simple route to extract cellulose from banana and orange peels was considered an innovation, and the researchers explained their application in water treatment using coagulation techniques.

1.5.1. Selection of Participants

The study involved 12 purposively selected third-year Bachelor of Science students majoring in Chemistry at a South African university. The selection was done by conducting semi-structured interviews with third-year Bachelor of Science students majoring in Chemistry. This was done to test their knowledge of PBL to corroborate quantitative findings. The students were divided into two groups consisting of six participants. Group A worked on banana peels while group B worked on orange peels. The students were assessed using worksheets to explore students' initial knowledge about how to clean wastewater and critical thinking processes. The worksheet assessed solution design, conceptual understanding, problem-solving, and critical thinking. Students were asked to identify existing water treatment techniques and possible ways to develop an efficient product for wastewater treatment. Students were given more than one chance to design the best product for wastewater treatment. Semi-structured interviews were administered to allow corroboration of findings emanating from assessment worksheets.

1.5.2. Design and Teaching of a Lesson Based on Water Treatment Activities

The lesson plan based on water treatment activities was developed and facilitated by the researchers to invoke students' knowledge to address the issue of novel materials development using waste to remove contaminants from water. The researchers raised the social issue regarding waste and the possibilities of using this waste in water treatment. Synthesis, separating mixtures, and plant composition were used to demonstrate to students the relationship between concepts in science, technology, engineering, and mathematics during the teaching and learning process. The lesson plan was developed based on the concept of a context-based STEM education learning approach [12]. The learning activities planned were also meant to enhance students' investigation skills and ability to design sustainable solutions to water problems. The context-based STEM education learning approach involves the identification of water issues and possible solutions, understanding the need for novel approaches, development of novel products, application of developed products in water treatment, and the evaluation of the solution achieved. The activities were informed to a large degree by challenges facing humans such as pollution, environmental issues, biotechnology, health, water issues, and designing of technological products. These stages assisted the students to apply scientific and other knowledge to design solutions and provided the instructional context required for solving real-world water problems. Students were also afforded opportunities to apply their scientific and other knowledge or skills to solve water problems [12,33]. The researchers provided opportunities for students to engage in an in-depth discussion on ground and surface water pollution. The disposal problems of agricultural wastes, especially fruit peels which are largely regarded as an ecological burden, were also discussed. In addition, the students were exposed to the benefits of the lignocellulose properties of waste. The synthesis procedure to develop valuable products and the properties of water, e.g., pH, turbidity, and material particle size were discussed. Worksheets were used to assess the acquisition of skills during the implementation of inquiry-based activities. Water treatment activities that involved the use of agricultural wastes are outlined in Table 1.

Table 1. Water treatment activities using agricultural wastes.

Stage	Activity
1. Identification of water issue	(1) Ask students to identify and discuss the sources of water pollution.
	(2) Teacher raises the issues, "How can students minimize water pollution and its effects? What are the health and environmental effects of water pollution?" "How can it affect humans and the local ecosystem?", "What are the methods that can be used to treat wastewater or leachate?"
	(3) Teacher focused more on the coagulation/flocculation method since it is an old and highly effective method for water purification.
2. Possible solution through PBL	Students and teachers discuss: **a.** The design of a simple route to extract cellulose from agricultural wastes considering the use of materials that are abundantly available and environmentally friendly (Biology and Technology). **b.** The sequence of processes that can be used to clean wastewater. **c.** Discussion on different particle sizes and their effects (Chemistry). **d.** Application of extracted cellulose from peels in water treatment using coagulation techniques (Engineering). **e.** Analysis of data obtained from water treatment using calculations (Mathematics). **f.** The mechanism behind the efficiency of cellulose extracted from the peels in water treatment (Science).
3. Classification of STEM-related subjects	Chemistry/Science (2 h) (1) Teacher revised the classification of mixtures according to particle size with the students, e.g., solution, colloids, and suspension. - Different ways of separating the dissolved solids from the liquid mixture were discussed. - Different water matrices and solution pH was discussed. (2) Teacher grouped the class into two, with six members in each group. Each group worked on one of the chosen agricultural wastes (banana or orange peels).
	Technology/Engineering (1) Provide each group with six beakers, jar test equipment, filter paper, kitchen blender, and pH meter. Let the students use the above-mentioned materials to develop a coagulant and set-up for a water treatment experiment. (2) Student wrote each step in the material synthesis on worksheets. (3a) Teacher explained that solutions have suspensions containing solids big enough to be affected by gravity. The suspended solids in this type of mixture could be separated from the liquid component by simply allowing it to stand for a certain amount of time. (3b) Teacher discussed the importance of slow and rapid mixing in the coagulation experiment.

Table 1. *Cont.*

Stage	Activity
	Mathematics (1) Teacher discussed data analysis with the students. (2) Different methods useful in analysing the data obtained from the experiment such as regression analysis, use of Microsoft excel to draw graphs. (3) Interpretation of data was also discussed. (4) Student used the above knowledge to present their results using the histogram on their worksheet. (5) Brief discussion of results was also written in their worksheets.

2. Data Collection and Analysis

The authenticity of the problem associated with STEM student inability to think critically to solve real problems has been established. Therefore, to explore PBL to eradicate this problem, direct laboratory teaching through experiential-based approaches to STEM education in water treatment was conducted using two groups of six students each. The students were then allowed to critically brainstorm on water solutions or the best products developed for turbidity reduction from water. The implementation of the designed product in water treatment, understanding the concepts through their critical thinking to solve the South African water problem, selection of information, assumption, and viewpoints on the solution, and the implication formed part of assessment worksheets completed by the students [22]. This approach brought forth the implementation of STEM education based on students' solutions by using different concepts to solve authentic problems beyond school walls. Data obtained from assessment worksheets were statistically analysed. The relationship between mathematical modelling and integrated STEM education in water treatment was explored during data analysis [8,34]. Semi-structured interviews were conducted with selected participants to corroborate quantitative findings.

Laboratory Experimental Procedure

The students first collected banana and orange peels from a nearby fruit market. As indicated before, students were grouped into Groups A and B, and they then experimented on banana and orange peels, respectively. The synthesis and application experiments were conducted in a university laboratory with all the necessary equipment and apparatuses. Banana peels and orange peels were gently removed from their fruits and were double washed with deionized water to remove the adhering dirt and then cut into smaller pieces. The peels were blended in a kitchen blender for about 20 min at 400 rpm using deionized water as a process control agent (see Figure 1). The peel particles were separated from cellulose using a <65 µm sieve and then stored in the refrigerator. Turbid water solution pH was adjusted using 0.1 NaOH and HCl purchased from Sigma Aldrich limited. The water used was sourced from the Bronkhorstspruit WTW and was found to contain the suspended solid with turbidity levels of 80.2 NTU. The volume of turbid water in each beaker was fixed at 500 mL for all the experiments [35].

Jar test experiments were conducted in 1 L beakers on each six-gang stirrer. The tests were conducted using processed banana peels coagulant (PBPC) and processed orange peels coagulant (POPC) by groups A and B, respectively. Rapid mixing of the solution was conducted for 3 min at 200 rpm, followed by slow mixing to allow floc formation for 20 min at 65 rpm. Finally, the water in the beakers was allowed to settle for 40 min. Samples were taken from 2.0 cm below the surface of the beakers for water analysis using a turbidity meter. The coagulant performance was evaluated by varying solution pH and coagulant dosage. The residual turbidity was measured using a turbidity meter. All chemicals were of analytical grade.



Figure 1. Schematic diagram of conversion of the agricultural wastes to coagulants.

3. Findings

The quantitative analysis was developed as a means for measuring the reduction of turbidity in water. The solution pH and coagulant dosage were used as process control parameters in this study. Although the pH of drinking water differs from one source to another, it ideally should be between pH 6.5–8.5. The performance of PBPC and POPC was evaluated at pH 2, 4, 6, and 8 using an initial turbidity level of 80.2 NTU. The turbidity of process water was first measured immediately after the settling stage and the results obtained indicated that the turbidity was reduced to slightly above 50 NTU in all pH ranges. However, after the separation of clean water and floccules formed in the process (see Figure 2), the turbidity of water was finally reduced to < 1 NTU at pH 2 for PBPC and pH 4 for POPC. The optimum pH obtained for both coagulants was then used to study the effects of coagulant dosage. An inverse relationship was observed between the coagulant dosage and turbidity reduction using the optimum pH for both coagulants separately. The data obtained from turbidity meter measurement were analysed using Microsoft Excel and the results were presented using a histogram graph in Figures 3 and 4 for PBPC and POPC, respectively.



Figure 2. Formation of floccules using PBPC in turbidity reduction.

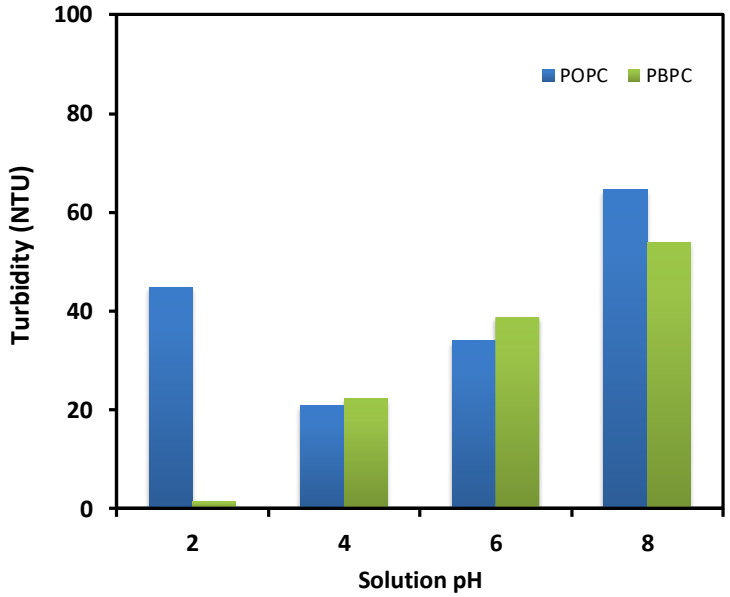


Figure 3. Effects of solution pH on turbidity reduction in water (dosage 2 mg/L, initial NTU 80.2 mg/L, volume 500 mL, temp. 25 °C).

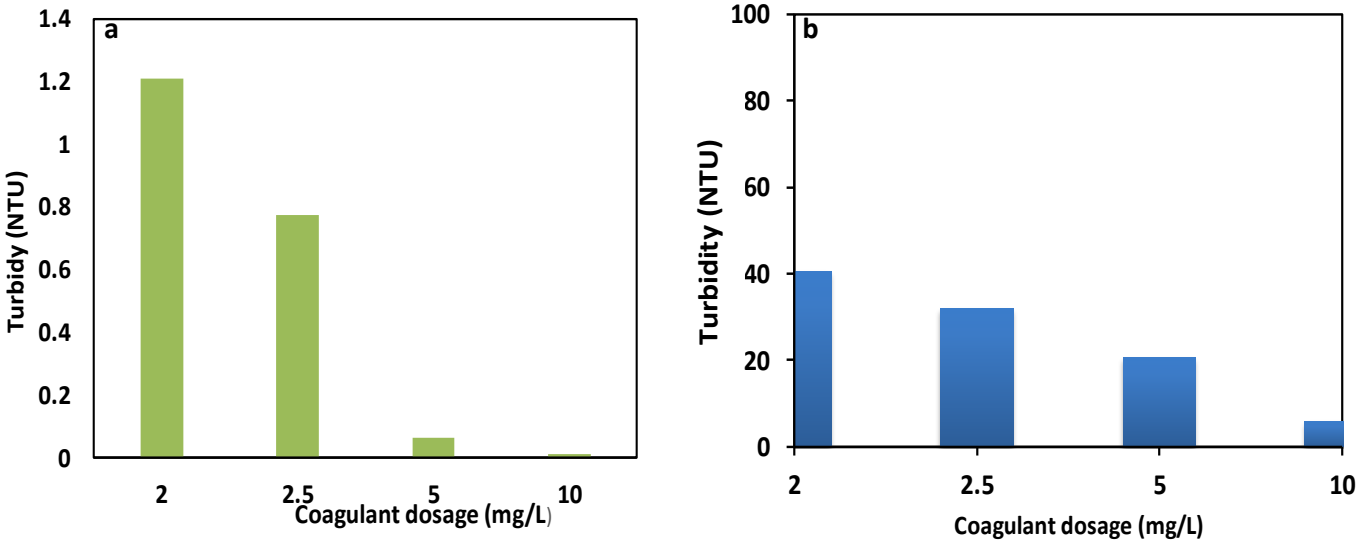


Figure 4. Effects of coagulant dose on turbidity reduction in water (**a**) PBPC, (**b**) POPC (initial NTU 80.2 mg/L, volume 500 mL, temp. 25 °C).

The turbidity level of the filtered water was expressed as a function of solution pH values in Figure 4, while Figure 4a,b displayed the effect of both PBPC and POPC dosage, respectively, in the reduction of turbidity. In both cases, an increase in coagulant from 2 to 10 reduces the turbidity from 80 NTU to <1 NTU which correlated to South African law (SANS 241:2015) [36]. This thus confirmed that the dose of approximately 10 mg/L is sufficient to achieve the requirement of filtered water turbidity which is <1 NTU.

Questions raised by the researchers during the class-based learning were: (1) How can waste be used to treat water? (2) Can agricultural waste be used as an efficient water treatment product in its natural form? (3) What are the effects of process variables such as pH and coagulant dosage on turbidity reduction or removal from water? Although students' responses to these questions were not satisfactory during the class-based learning, their naïve understanding was addressed during the laboratory experiment. The students' experience in coagulant preparation and water treatment activities enhanced

their understanding of the chemistry of interaction between PBPC/POPC and turbid water. Group A with the assistance of researchers confirmed that banana peels contain about 70% cellulose [37] and this product might be responsible for its higher performance in turbidity reduction. Group B also found that the presence of certain functional groups such as carbonyl and hydroxyl groups in orange peels could be responsible for its performance in turbidity reduction [38]. The findings strongly suggest that water treatment activity facilitated the development of STEM students' critical thinking skills.

The students expressed fundamental appreciation of the affordances of inquiry-based activity such as water treatment activity in the development of investigation skills and critical thinking skills as reflected in the following excerpt from interviews.

- The water treatment activity was challenging and encouraged us to apply our minds to find solutions to water problems. The activity required the application of interdisciplinary scientific knowledge to develop sustainable solutions for water problems.

The students were also fascinated by the effects of coagulant dose on turbidity reduction in water. This observation served to reinforce students' understanding of various water treatment techniques as the following excerpt demonstrates.

- The complexity of prevailing water problems requires a clear understanding of water treatment techniques. Water is a precious resource and there is a need for us STEM students to be adequately trained in water treatment techniques to ensure that safe and drinkable water can be provided to communities on a sustainable basis.

As a follow-up task, students were tasked to research the ability of banana peels and orange peels to reduce water turbidity. The researchers intended the students to identify and explain the processes involved based on the previous concepts learned in Chemistry courses.

4. Discussion

It was generally observed that when coagulant was introduced in the turbid water, the level of turbidity was lowered. This could be explained using the electro-kinetic properties of suspended solids in water and the charges on coagulants. Suspended solids are usually negatively charged and due to the repulsive forces, they were spread in water resulting in high turbidity levels [39]. The suspended solids were destabilized when the coagulant was introduced. Therefore, van der Waals forces and surface adsorption became dominant. Subsequently, the suspended particles developed floccules together and the sediment particles were easily removed by filtration which then resulted in low water turbidity. Indeed, a target <1 NTU (SANS 241:2015) was achieved for the turbidity level of filtered water, suggesting that PBPC and POPC could be a potential coagulant with application value [40]. However, it was observed that enhanced turbidity reduction was achieved with the use of PBPC compared to POPC. This might be attributed to the higher quantity of cellulose in banana peels [41]. STEM activity in water treatment is related to scientific concepts such as density of water, acidity, alkalinity, turbidity, and other quality water parameters, and the enormous utilization of science knowledge by the participants [42]. Technology requires students to find out additional information about how to design and develop novel water treatment materials. Engineering requires students to design effective and efficient water treatment equipment such as purifiers or jar testers while the field of mathematics requires students to model the data collected using some calculations or mathematical modelling related to the design of the water treatment [43]. The expectation of STEM knowledge was met during this experiment. For example, two novel materials (PBPC and POPC) were developed, water treatment was successfully conducted to reduce the turbidity in water, and mathematical regression analysis was used to present the findings [44,45]. Inquiry-embedded PBL has great potential to enhance students' critical thinking skills using water treatment activities in particular.

The identification of water pollution-related problems is in line with the list of South African national priorities as the nation ranks as one of the 30 driest countries in the

world [46]. The researchers discovered the presence of functional groups embedded in agricultural wastes which could be responsible for their efficiency in water treatment. The water treatment activities implemented by Groups A and B demonstrated that the performance of PBPC in turbidity reduction is higher than that of POPC. Although the coagulant development was designed by the researchers, each group decided the best way to carry out the process using a kitchen blender. For example, Group A used 300 rpm speed to blend banana peels which came out very fine and smooth, while group B decided to use 200 rpm. Both groups tested the performance of their developed coagulant in turbid water using jar test equipment. The same specifications such as rapid mixing, slow mixing, and settling time were adopted by both groups. PBPC and POPC were delivered, together with their obtained results from wastewater treatment. As such, the performance of both coagulants in turbidity reduction complied with the South African National Standard (SANS241) for drinking water quality [47]. As part of the underlying theoretical framework, the Five Steps of Project-Based Learning enabled the participants in each group to carry out the water treatment activity.

5. Conclusions

The best way to confront water challenges is by involving the citizens in water treatment and management through the advancement of STEM education. Therefore, this study presents an approach on how to provide STEM education through team teaching based on project-based learning. Although, the learner is the focus but the centrality of the teacher to guide the inquiry through PBL to achieve the set goal is critical. Therefore, the identification of potential solutions through the use of agricultural wastes can serve as an effective means to enhance students' critical thinking required to develop ideas for novel products. This thus enhanced the active exploration by students through participation in PBL. The need for the replacement of existing chemically synthesized coagulants with more environmentally friendly agricultural wastes encouraged the students to think critically. The water treatment activity provided meaningful platforms for students to apply interdisciplinary knowledge. Moreover, their understanding of the basic knowledge of the Five Steps of Project-Based Learning assisted the participants in each group to carry out the water treatment activity. Although, the researcher's connections and guidance made the student work more visible and easy to follow, however, the set goal with regard to the improvement of their critical thinking was achieved. Therefore, harnessing project-based learning as a means to enhance STEM students' critical thinking skills using inquiry-based activities such as water treatment activity is one of the potential approaches to improve the STEM student.

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