THE PROJECT-BASED LEARNING'S KEY CHARACTERISTIC: HOW STEAM SPARKS CREATIVITY AND CURIOSITY IN CULTIVATING *Daphnia sp.* ACID BASED CHEMISTRY

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ARTICLE INFO	ABSTRACT
Keywords: *Chemistry;* *Creativity;* *Curiosity;* *STEAM;* *Projects Based Learning.* *Article History:* *Received: 2024-09-09* *Accepted: 2024-11-17* *Published: 2024-12-25* *d*oi:10.20961/jkpk.v9i3.93190 	Chemistry Education in High School Integration of STEAM (Science, Technology, Engineering, Arts, Mathematics) with Project-Based Learning (PBL) to Enhance Creativity in Students 11th-grade students created a *Daphnia sp.* cultivation pond, an experience with transformative learning involving interdisciplinary knowledge as well as collaboration and critical thinking skills so vital to the 21st century. Data were collected using questionnaires, interviews, and student worksheets with a qualitative case study approach. This study closely examines six pivotal aspects of STEM-PBL, which are driving questions, learning goals, scientific practice, collaboration, technological tool use, and artifact creation—because creativity and curiosity are the target outcomes of STEM-PBL. These results showed a strong positive correlation in students' cognitive positive skills, complemented by the STEAM-PBL approach in six main characteristics of STEAM-PBL. The study found no significant association between curiosity and cognitive scores, indicating that curiosity may develop separately from direct academic performance in this framework. While these findings are quite positive, the study also found challenges such as limited resources, lack of teacher training programs, and resistance towards traditional forms of education. The research suggests continued investigation into the long-term effects of STEAM-PBL and its relevant use in other learning environments.

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INTRODUCTION

The lives of young people and their values, behavior, and interpersonal relationships have been dramatically shaped by rapid technological advances, globalization, and the permeation of social media into society. This development enables us to determine and assess the competencies necessary for each field from diverse technological, pedagogical, contextual, and humanistic perspectives [1]. The 21st-century skills framework gives tips to filter out those competencies students need to acquire to succeed in the next generations, indicating whether the existing competencies and learning methods will lead students to achieve this [1]. One of the reasons we need to provide instruction on character education to students is among the frameworks of 21st-century education that fit well in today's context. Therefore, character education in Indonesia is a systematic implementation continuously formed through pedagogical activities and practices characterized by religious principles and cultural values. The philosophical doctrine of Pancasila should be carried out and developed [2], [3]. A holistic approach to character education develops students' knowledge of ethical principles, their motivation to apply these principles, and the habits of action derived from their values.

The Ministry of Education and Culture has arranged for Strengthening Character Education (PPK) to be integrated into the national education system, namely developing students' characters through various educational activities and integration of the curriculum [2], [3]. Thus, the above national higher education policy aims to develop students' general and special (professional, disciplinary) competencies, such as creativity and curiosity [4]. The performance of research for interpreting and reducing distress founded on the scientific method should be included in the educational systems becomes a need for humanity [5]. In project-based learning (PBL), ways to use student-centered learning (PBL) can be an actual strategy in problem-oriented science or for encouragement [6].

Project Based Learning is an inquiry-based instructional strategy that engages students in learning as they build knowledge while working on meaningful projects and generating products of value [7]. If future generations then have to be able to cope with global environmental problems [6], students have to participate in such commutative practices in institutions of education. Collaborative Learning is essential in implementing the PBL concept. Science education should, therefore, provide students with rich learning instead of factual memorization of facts that can be used immediately; students should learn to consider how they can use and apply scientific ideas and practices to make decisions in science [8]. Discoveries have indicated that students taught through PBL outperform those taught through teacher-led instruction [6], [9], [10]. PBL has also enhanced students' critical thinking, creativity, and ability to pose questions [6].

The implementation and impact of Project-Based Learning (PBL) on student outcomes have been discussed more thoroughly in several studies. In implementation, most of the studies describe course scope, instructor roles, and team dynamics, and impact studies describe PBL's impact on cognitive [for example, knowledge-acquiring] and affective [for example, creativity and curiosity] outcomes [11]. So, PBL develops students' metacognitive skills through self-directed learning and challenges them to perform self-assessment and evaluation [9]. PBL is thus indispensable for gaining critical knowledge and developing many skills, including creativity and asking the right questions [6].

PBL is widely used in other fields, particularly in science and mathematics, such as chemistry, to deepen students' understanding of scientific concepts and apply problem-solving techniques in project execution [9], [12]. So, integrating PBL with science education can help students investigate and apply scientific principles through practical activities, thereby creating a greater understanding of the content and the scientific process and a passion for the subject matter [12]. Integrating art into STEM, STEAM (science, technology, engineering, arts, mathematics) also broadens the scope of this process. With the addition of the arts, STEAM promotes creativity, curiosity, and cross-disciplinary studies, providing students with a more comprehensive learning environment [13], [14], [15].

This STEAM-integrated PBL leads students through real-world relevant projects and teaches 21st-century skills like collaboration, communication, and problem-solving [14]. Daily name acid and bases and chemistry topics can be interesting if you take these examples in your work. Firstly, a project designing a *Daphnia sp*. The science problem-solving may be combined with an artistic approach in developing Instagram reel videos, allowing students to engage in practical application studies and enjoy learning [14], [15], [16]. This combination guarantees that children don't just learn but also develop essential life skills.

Water fleas (*Daphnia sp.*) are important components in freshwater ecosystems; they are important primary consumers, feeding on algae and bacteria. In aquaculture, live feed plays an important role, and their nutritional value and easy growth make them valuable in this respect. The *Daphnia sp*. intermediate level science technology arts and mathematics (STEAM)-integrated project described in this study Theoretical chemistry is essentially the application of scientific knowledge (especially regarding pH values). The *Daphnia sp*. is designed with the help of digital technology, and the project results are shown through Instagram reels and pond outlines. Mathematics undergirds quantitative pH analysis, while arts elevate the aesthetic of the project and situate chemistry in a social context [17]. Time and resource limitations meant that the engineering aspect of STEAM was left out in favor of deeper explorations into the other STEAM disciplines, which is arguably a continuance of the challenge of integrating all STEAM disciplines.

This study introduced a pilot program integrating STEAM and project-based learning (PBL) to overcome limitations and engage students. The framework articulated the program in six stages: (1) posed driving questions, (2) realized learning goals, (3) followed scientific practices, (4) shaped collaboration, (5) used technological tools, and (6) designed an artifact [8], [18]. This small-group learning model engaged students in practical problem-solving and facilitated deeper inquiry and critical thinking around scientific concepts.

This research focused primarily on the step-by-step implementation of the STEAM-PBL model and its effectiveness in promoting students' creativity and curiosity—two of the most important 21st-century skills. In this way, the Character Initiative uses the Strengthening Character Education philosophy to build humans who are balanced, innovative, and socially responsible humans within a practical framework. This document emphasizes how STEAM-PBL will enable educators to design more engaging, meaningful, and relevant learning environments that prepare students to meet real-world challenges.

METHODS

1. Research Design

This research aims to examine the aspects of STEAM-PBL and its effect on creativity and curiosity among high school students in chemistry education. This qualitative study describes the influence of STEAM learning on the creativity and curiosity of high school chemistry students. Qualitative research using regression to determine the effect of STEAM-PBL on creativity and curiosity.

2. Participants

The study's participants were one high school of public-school students in Indonesia. Science class students participating in this research were selected randomly regardless of any criteria. Our study featured 62 students of different ages, genders, and grades. Table 1 depicts the participant's demographic information.

Table 1. Participant Demographic

Variable		***Frequency***
Range Age		14-16
Year of Study		2^{nd}
Sex	*Female*	18 / 29,04%
	Male	44 / 70,97%
Total		62

3. Instruments

Instruments, including a questionnaire, interview instrument, and LKPD, were created and validated by an expert, after which they were given to students and teachers. The acid-base LKPD knowledge scores of the students who accepted LKPD consisted of 11 questions concerning *Daphnia sp*. cultivation issues. These ranged from identifying the problem to understanding the problem, developing hypotheses and analyzing problems, identifying cultivation pond indicators, and applying solutions and conclusions. At the same time, two categories of questionnaires were made: one for creativity and another for curiosity. All the indicators of the creativity questionnaire include originality, fluency, flexibility, and elaboration [19], [20]. The curiosity questionnaire variables included the wish to learn novel things, eagerness to engage in learning, and ability to coordinate existing cognitive structures (known) and build them with reality [21], [22]. The creativity questionnaire was based on seven open-ended questions, prompting students to write as many responses as possible within the provided limitations. Creativity and curiosity test components Tables 2 and 3 show the components of the creativity and curiosity tests, respectively, which were a 20-item curiosity questionnaire and a novelty-based creativity test, given through Google Forms using a Likert scale (1–5) from "strongly disagree" to "strongly agree."

Table 2. Creativity Indicators

Test Components	Question Indicators
Word Formation	Students can form as many words as possible using one starting letter related to chemistry topics.
Word Formation	Students can form as many words as possible using two starting letters related to chemistry topics.
Word Arrangement	Students can arrange three words from the given letters related to chemistry topics.
Unusual Uses	Students can think of many unusual uses for a given object.
Cause and Effect	Students can think of the consequences of a given event.
Similar Properties	Students can find as many objects as possible that share two given properties.
Idea Generation	Students can generate ideas or concepts from a given topic.

Table 3. Curiosity Indicators

Dimensions	Statement Indicators
Joyous Exploration	Students seek new knowledge and information and experience the joy of learning.
Thrill Seeking	Students are willing to take physical, social, and financial risks to gain varied and complex experiences.
Deprivation Sensitivity	Students solve problems and strive to reduce gaps in their knowledge.
Stress Tolerance	Students can tolerate discomforts arising from exploration, new experiences, and unexpected events.
Social Curiosity	Students are curious about what others do and think.

4. Procedure

The chosen topic of focus was acids and bases, with students challenged to create a *Daphnia sp*. cultivation pond and share its design on Instagram reels. The collection of descriptive data was conducted employing adaptations of the PBL pedagogy design concept [5], [6], [8] proposed by several experts in the field of PBL and 21st-century learning concepts.

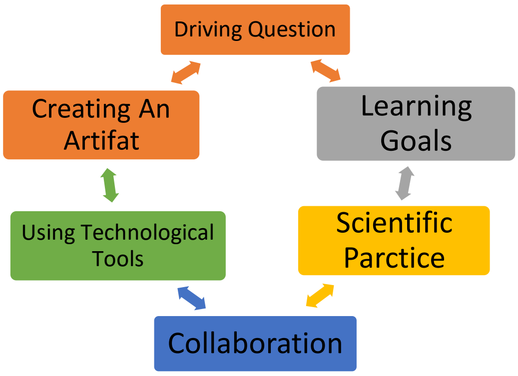

Figure 1. STEAM-PBL design concepts.

5. Procedure

The topic of choice was acids and bases, where students had to design a *Daphnia sp*. plant pond and showcase their designs on Instagram reels. Descriptive data was collected using adaptations from the concept of PBL pedagogical design proposed by some of the PBL and 21st-century learning experts from the literature. Data Analysis

Thematic analysis was used to transcribe interviews and observation notes, focusing on identifying patterns and themes concerning creativity and curiosity. A quantitative analysis was performed from the questionnaire data regarding altering students' creativity and curiosity. The effects of STEAM learning on students' cognitive performance were also assessed to explore its impact on creativity and curiosity—ing concepts [5], [6], [8].

RESULTS AND DISCUSSION

1. STEAM-PBL Design

Project-based learning (PBL) states that students must investigate relevant phenomena in-depth using scientific principles. This, in turn, made learning in practice take place longer than in traditional learning models [23]. The prioritized characteristic of perfect purposes prominent in PBL should cover developing 21st-century skills, student-centered learning, and enough individual interaction between students and teachers [24]. This will take teachers fulfilling their end of the bargain and students fulfilling their end. Teaching is not an easy task (even) in the Project-based learning (PBL) model, where it is common to become designers, advocates, facilitators, and administrators simultaneously, and the students need to be self-directed students able to withstand any uncertainty and openness in PBL projects [25]. For this study, the six key characteristics, according to Krajcik and Shin [8] shown in Table 4, were selected as a content analysis framework and used to investigate the PBL units.

Table 4. The chosen framework for the category used and rationale for the category of STEAM-PBL

Characteristic	Category used in the analysis	Rationale for the category
1. Driving question	The subsequent characteristics delineate a compelling driving question within the context of STEAM-PBL. [26]: 1. The driving question is authentically linked to the real world experienced by the students, and it is interesting to them. 2. The driving question is open-ended, challenging the students to carry out intellectually challenging tasks, considering their age and skill set. 3. The driving question requires understanding the central scientific concepts related to the studied subject.	This research included the three driving questions within the context of STEAM-PBL, which are under "3. Scientific practices." Additionally, due to the level of detail in the chemistry materials, environmental learning was considered in the wider sense of the term.
2. Learning goals	Learning goals stated by students and teachers: 1. Learn new topic and skill 2. Gain deeper understanding	The second aspect of this key characteristic was chosen as the focus: Did the teachers and students report any learning skills and understanding because of the projects?
3. Scientific practice	Using scientific methods to solve and study driving questions [6]: 1. Conceptualization a. Presenting research question b. Explore hypothesis 2. Observations a. experiments b. data interpretation 3. Conclusion 4. Discussion a. communicating the result b. reflection	This stage describes the scientific methods students practice in a research project. The first phase," orientation," was left out, and the driving question was studied separately.
4. Collaboration	Collaboration between student & student; student & teachers	These classifications emerged from the utilized resources.
5. Using technological tools	1. ICT (Information and Communication Technologies) 2. Technology used in scientific practice	Technology is used to create artifacts and support student learning, such as increased interest, modeling concepts, and strategic support.
6. Creating an artifact	Producing an artifact or a product that answers driving questions: one clear artifact	Krajcik and Shin (Markula & Aksela, 2022) stated that the artifact should answer the driving question, reveal the students' level of understanding, and improve students' understanding of the topic. However, using all of them in this research was impossible due to the lack of driving questions and details about the projects' aims.

Both artifacts and driving questions would likely require additional instruction [23]. The researcher created projects using three driving questions from Table 3, including links to real-world problems, open-ended questions, and concepts from scientific content. This is a design problem, and the students and teacher explore and answer this question. It creates a context for all activities and investigations [23]. It enables the student to learn to use this framework and, therefore, supports the student's ability to 'see the interconnectedness' that helps with the enhancement of students' compound understanding [8], [23]. Researchers look at knowledge, understanding, and skill growth in learning objectives, such as creativity and curiosity. Qureshi [7] asserts that PBL is beneficial because it always teaches students new skills and new information, which is the key part of the course, thus enhancing the educational scheme [6]. This research uses scientific concepts to create and bring an end to projects. The stage of scientific concepts is defined as the activities students are engaged in when implementing a project. En esta actividad los alumnos realizan un trabajo cooperativo en el momento de hacer el proyecto. In PBL, students work in teams, dividing roles, assisting and supporting each other, seeking information, sharing experiences, designing activities, and reflecting on knowledge and social skills necessary for lifelong learning [28]. The team spirit will be cultivated, unexpected issues will be researched, and resources will be well organized [4]. However, artifacts should answer the driving question and coalesce the project [6]. An artifact was made using digital technology as a communication tool. Digital technology was an essential part of developing artifacts and became a means of communication. Instagram reel is the media communication used to disseminate the final project.

Collaborative and project-based learning models have effectively improved student engagement and understanding, especially in science, technology, engineering, arts, and mathematics (STEAM) fields [29]. This enables educators to provide lessons focused on processes and integrate art into STEAM projects to create well-rounded lessons that allow students to experience the work [12]. In this study, students were asked to design a pond for growing *Daphnia sp*., integrating math, science, tech, and the arts into their project work.

Using mathematics to calculate the compounds required to adjust a person's pH and pond dimensions required for a certain volume of water. These calculations demonstrated that acid-base concepts were not just theoretical but critical to growing a successful Daphnia sp incubation. Such a theoretical knowledge of the science behind acid-base concepts enabled each student to appreciate the chemical interactions necessary to produce and sustain the best pond culture circumstances.

Technology has become a tool, a design tool, and a communication channel. Daphnia sp. were created using digital tools such as computers and laptops. Pond designs and platforms like Instagram allowed students to share final projects, encouraging communication and collaboration through digital media. The arts were instrumental in embedding aesthetic values in the project's results and fostering visual literacy. Using art elements to explain the acid-base concepts in a concept map format made the scientific concepts more approachable and engaging. This visionary approach of STEAM fosters transdisciplinary understanding, integrating individuals from different disciplines and backgrounds to inspire innovation and reproductive education [29].

2. STEAM-PBL Implementation

STEAM-based learning was integrated with 11th grade, where learners focused on pH calculations with acids and bases. We selected this topic to draw connections with mathematics, technology, engineering, science, and art. The three-step process used to solve the problem was

Daphnia sp. divergent thinking, in which students were first given general information about a topic and then some problem relating to a particular scenario that students can resolve.

Participants in this study were high schoolers from a public school in Indonesia. The school hails from a suburban region and a rural one. The subjects were randomly chosen without any criteria from class science. In PBL, a collaborative team structure is employed, and all students are classified into assigned teams. The group should be 3-4 students. Figure 2 demonstrates how this learning process is applied. The two schools yielded various outcomes considering the differences in educational background and school learning culture.

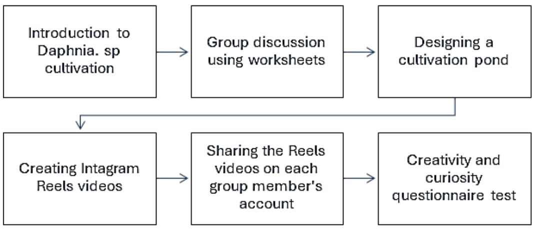

Figure 2. Steps of Learning Implementation

Table 5. Time Distribution of the projects of *Daphnia sp.* in STEAM-PBL

Scientific Practice	Time allocation
1. Conceptualization	
a. Presenting research question	1^{st} – meetings
b. Explore hypothesis	1^{st} – meetings
2. Observations	
a. Experiments	2^{nd} – 3^{rd} meetings
b. data interpretation	2^{nd} – 3^{rd} meetings
3. Conclusion	3^{rd} – meetings
4. Discussion	4^{th} – meetings
a. communicating the result	4^{th} – meetings
b. reflection	

In four meetings, the high school students also laid the foundation for the project. Thus, this course involved scientific practice, starting by framing driving questions and followed by final products. The time allocated to the scientific practices is presented in Table 5. Each activity required a total of two hours/80 minutes of classes.

3. STEAM-PBL Reflection

The model proposed by Krajcik & Shin [6] was the most recent and detailed description of the characteristics of PBL during the analysis, which enabled the quality of the PBL units to be examined empirically [6]. Table 6. Research, implementation, and STEAM-PBL components.

Table 4 Characteristics of an effective GIQ (from Bormann—2014 [24]). This resonates with research done by Morrison et al. [24], who found that students are highly aware of the authentic nature and engagement with real-life problems central to PBL. An engaging driving question creates an intense desire to learn among students [30] and pushes students to recognize that a real problem needs to be addressed [31]. While seeking solutions to the driving question, students develop a holistic understanding of key scientific ideas [32]. The real driving question forms the initial stage of each unit STEAM-PBL design in this study.

Only one- clear task has been divided as per the theme of driving questions to 2 client tasks for the solution. Identifying the best solution to keep pH value significant concerning *Daphnia sp.* habitat. And specification ponds for *Daphnia sp.* to promote the growing of this species to farmers. These real-life questions can motivate the students to learn the acid-base concept in chemistry. By STEAM concepts, problems that can only be solved by knowledge from one discipline need not be complex from the integrated STEAM perspective [33]. The projects require science, specifically chemistry, to find solutions and other disciplines such as mathematics, arts, and technology. According to the theory of situated learning [16], [34], if individuals are provided with opportunities to engage in contextually relevant learning and combine them with experiences and prior knowledge, students can relate what they are learning to what they have already learned, thereby improving conceptual understanding.

Table 6. Visibility of key characteristics and their implementation in practice in the STEAM-PBL units

Key characteristic		Implementation	STEAM components
Driving question	1. The driving question is authentically linked to the real world experienced by the students, and it is interesting to them.	The problem is an environmental issue related to everyday life. The cultivation of Daphnia Sp. It aims to assist farmers in the strategic design of ponds conducive to the habitat requirements of Daphnia Sp.	Science Technology Mathematics
	2. The driving question is open-ended, challenging the students to carry out intellectually challenging tasks while considering their age and skill set.	All the questions are open-ended. For example, student worksheets (LKPD)	
	3. The driving question requires understanding the central scientific concepts related to the studied subject.	The projects required an in-depth understanding of pH concepts to determine the amount of water and chemical compounds used.	
Learning goals	Learns new topics and skill	In this research, students' skills in creativity and curiosity improve	Science Technology Arts Mathematics
	Gain deeper understanding	Students' understanding of acid-base concepts increased, including pH and buffer concepts.	
Scientific Practice	Asking question Forming hypothesis Experiment and Exploration Interpreting data and conclusion	All the stages are on the student's worksheet (LKPD). Students carry out scientific practice based on the stages that have been arranged in the LKPD	Science Technology Arts Mathematics
	Communicating	Teachers use social media, such as Instagram reels, to present the final products.	
	Reflecting	At every phase of the instructional process, the teachers engage in critical reflection and offer constructive feedback on the student's work results.	
Collaboration	Student & students	They work as a team or group to solve the problem and create artifacts	Science Technology Mathematics
	Student & teachers	Teachers give suggestions to help students pass on the challenges that are faced.	
Using technology Tool	ICT (Information and Communication Technologies)	Students employ digital technology to complete projects, including computers and the Internet.	Technology
Creating an artifact	Producing an artifact or an end product that answers driving questions: one clear artifact	Outline of Daphnia Sp pond as a final product. Students can engage their creative capacities in designing ponds to cultivate Daphnia Sp.	Science Technology Arts Mathematics

Incorporating technology, engineering, art, and mathematics into chemistry education, STEAM learning enables students to experience how chemical principles are applied in real life and demonstrations of industry utilizing chemical processes, thus making learning more relevant and engaging [10], [35]. Engaging with art in the context of learning chemistry can make the material more interesting and motivate students. STEAM-PBL encourages creativity as learners immerse themselves in solutions to real-world problems [13], [36]. The benefits of learning through STEAM-PBL allow students to develop insights about chemistry [37]. The driving question is about finding out what pH value is relevant to the habitat of *Daphnia sp*. The students do not only get to know pH but also get to know buffer concepts and the way to preserve the pH value of *Daphnia sp.* Can relate to real-world, original problems; complicated issues must not have a clear-cut solution, and at least two alternatives must exist [33].

This STEAM-PBL was addressed through scientific practice and collaborative learning in the projects. Studying phenomena, wondering about them, engaging in their ideas, engaging in science, critiquing the ideas of others, trying out creative solutions, and building and refining models are all qualities of scientific practice [32]. The driving question is explored through students engaging in scientific practices to create an artifact [34]. Sharing and discussing ideas helps students develop scientific practice. Collaboration is a systematic, concurrent process of continuous work to create and maintain a shared understanding of a domain [32]. Collaboration in PBL is not common cooperation but is reflected in how problems are solved [32]. Studies have shown that students benefit significantly from small-group learning environments [27], [38]. Peer collaborative groups help individuals be more motivated and succeed more than those not in a collaborative group regarding their reasoning and critical thinking abilities [27] in the farming project of *Daphnia sp.* Students work in a group.

The final essential quality is producing an artifact. The Artifact is the response to the central inquiry of the projects. All of these ensure that in this research, a researcher creates a product with a new skill: curiosity and creativity. This should be about the learning rather than the project delivery — the teachers' focus should be on what the students can simultaneously inquire and determine, not what students can create and achieve [39]. The projects seemed a series of poorly linked lessons that were either too conceptually motivated, assuming similar, pre-determined outcomes for all students, or a kind of research activity, where the goal was to search about a particular object without any concrete outcome [40].

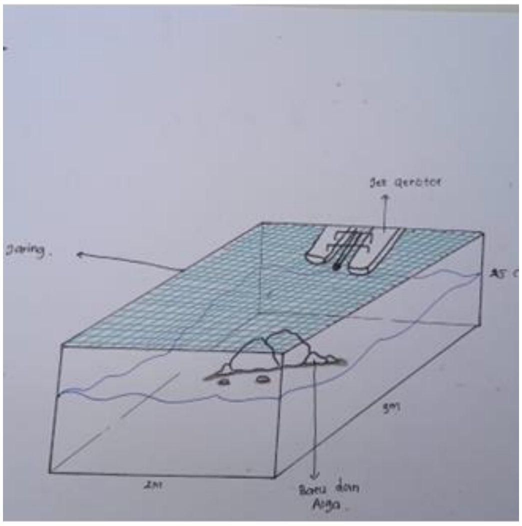

Figure 3. Student's *Daphnia sp*. Cultivation Pond Design

These high school students then designed and created video reels of a *Daphnia sp*. cultivation pond. The students then filled out a Google Form questionnaire to measure their creativity and curiosity levels and filled out the LKPD at the end of the lesson. Students created their designs using information learned in the lesson and from outside research using books or internet sources. Students were also asked to document their process as a short video to share as an Instagram reel to reach a larger general audience and distribute the information our lab has uncovered about *Daphnia sp*. cultivation. This transition from simply absorbing new information to actively seeking it out inevitably made me more curious and eager to learn. Involvement in designing ponds for the breeding of *Daphnia sp*. is expected to boost student creativity and enhance innovation. Figure 3 shows the project result, and Figure 4 shows Instagram for social media sharing of the final product.

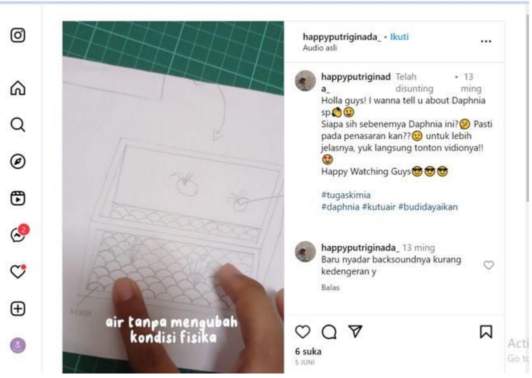

Figure 4. Student's Instagram Reels

The relation between students ` levels of curiosity and their cognitive score about acids and bases, the regression analysis results for curiosity were carried out. The curiosity questionnaire was administered after the STEAM-based acids and bases lessons. In the questions regarding the curiosity indicators, students were asked to choose statements according to the Likert scale about the indicators of curiosity: joyful exploration, thrill-seeking, deprivation sensitivity, stress tolerance, and social curiosity [22]. Based on these five broad dimensions, 20 statements were created and presented to students through Google Forms.

As revealed in Table 7, the curiosity variable does not impact students' cognitive scores regarding this topic. Amazingly, in projects of *Daphnia sp*. cultivation, teachers do not enhance students' curiosity. Curiosity is not mediated by knowledge and STEAM-based learning. By analyzing Table 3: Curiosity Indicators and Table 7: Regression Test of Curiosity and Cognitive Values correlation, two patterns arise, especially the positive correlation between students with high curiosity per the cognitive scores within our PBL settings, perhaps it can also signify that although students are curious that doesn't necessarily beget cognitive value. Curiosity, as discussed via joyous exploration, thrill-seeking, deprivation sensitivity, stress tolerance, and social curiosity, is a diverse, multi-faceted construct motivated largely intrinsically by a desire to seek out novel knowledge [21]. Yet this curiosity does not naturally align with the formalized metrics of academic prowess often ascertained by cognitive tests. The high level of student engagement with the project [normally following five categories of engagement: behavioral, affective, cognitive, social, and agentic engagement] did not translate into performance improvements in knowledge retention or problem-solving, specifically in chemistry, using standardized testing [41].

The target curiosity indicator enabled the STEAM-PBL to design the *Daphnia sp.* pond and film Instagram reels. For example, joyful exploration and the students' excitement to explore new concepts resulted in students detailing their understanding of biological and chemical factors necessary for Daphnia cultivation. For example, thrill-seeking pushed students to experiment with creating innovative approaches to learning, including designing visually stimulating reels to demonstrate their learning, evoking a richer connection to the learning material. Deprivation sensitivity and the desire to inquire into knowledge gaps helped students investigate the spatial and temporal environmental conditions needed to support optimal growth of *Daphnia sp*. and bridged scientific investigation with project outcomes. Through the iterative design process, designing and troubleshooting both the pond system and the accompanying reels, stress tolerance was vital — students had to deal with what they came across without becoming overwhelmed. Finally, we fostered social curiosity with group exercises, as students learned from one another, contributed to discussions, and shared moments, enhancing learning.

Perhaps this gap is due to the characteristics of the STEAM-PBL ecosystem, where learning takes place in a multidisciplinary context, focusing on creativity and application to the real world [42], [43] rather than emphasizing academic performance. The difference is that through project-based learning, students engage with content in a more applied, experiential fashion, igniting curiosity but not necessarily reinforcing the precise academic knowledge that standardized tests measure. In addition, curiosity-driven learning tends to prioritize open-ended exploration, with students pursuing their interests, which may lack the focus on structured problem-solving skills measured in cognitive environments. In other words, this indicates that curiosity is critical to the continuation of this drive, engagement, and ideation; however, it does not imply that higher-order thinking is more likely in cases where curiosity behaved in an exploratory manner unless direct correlations between this propensity and the academic goals of interest/concern are made.

Table 7. Results of the Regression Test of Curiosity and Cognitive Values

Metrics/Variables	Value
Regression Sum of Squares	0.116
Residual Sum of Squares	17.208
Total Sum of Squares	17.324
F-Statistic	0.403
Significance (Sig.)	0.528
Dependent Variable	Cognitive Values
Predictor Variable	Curiosity
Unstandardized Coefficients (B)	Std. Error
Constant	1.011
Curiosity	-0.091

Table 8 shows a significant regression between the creativity and cognitive variables. The result significance value obtained is (0.014<0.05), indicating that H_o is rejected, which means it can be said that creativity affects the cognitive obtained by high school students in chemistry. This was due to the learning method, which featured stages that involved working on a project, specifically designing a *Daphnia sp*. cultivation pond and producing video reels, which were compulsory for every group. Students were allowed to express their ideas freely when designing these products.

Table 8. Results of the Regression Test of Creativity and Cognitive Values

Metrics/Variables	Value
Regression Sum of Squares	333.504
Residual Sum of Squares	3140.383
Total Sum of Squares	3473.887
F-Statistic	6.372
Significance (Sig.)	0.014
Dependent Variable	Cognitive Values
Predictor Variable	Creativity
Unstandardized Coefficients (B)	Std. Error
Constant	74.619
Creativity	0.145

Creativity dimensions evaluated in this study according to their test components, including word formation, word arrangement, unusual functions, causation and consequence, similar properties, and idea generation (Table 2). These components aimed to measure students' creativity, as the creativity of students was queried for different topics in chemistry, such as forming words associated with different topics, arranging letters, etc.

The results show a positive relationship between creative abilities and cognitive elements, confirming that students with more creative skills also have more cognitive values in chemistry. This is consistent with previous studies that indicate that learning through creating projects and STEAM can lead to a more thorough understanding of and retention of complex topics [44], [45].

On the other hand, STEAM-PBL plays a big part in students' creativity development in a positively correlated project. The positive correlation in the dimensions of word formation and word arrangement gives us an understanding that could help determine that the higher the success of the students in word formation and arrangement activities, so it is reasonable to assume that they improved the retention of vocabulary and concepts related to the chemical sciences, so we require an internal organization of concepts acquired, by promoting better cognitive processing at the expense of the production cycle of the conceptual framework of our students which can lead to a greater understanding of the student's mental framework. This competency is particularly important for students when designing a project as they develop a driving question. Bell [44] stated that using PBL opens students' minds to explore how tasks may be approached, strengthening student creativity.

The unusual use of dimension tests directly affects the students' flexibility in thinking in the sense of coming up with multiple solutions or ideas from the same base [20]. When students have just delivered driving questions or questions that have been issued, they implement imagination, stretching the standard associations to yield new ideas or solutions from driving questions. The cause-and-effect dimension engages students in making hypotheses and predicting outcomes, which is the essence of any science [19], [20], [45]. This analytical thinking involves causal connections between the overall process and its sub-processes [44]. It is an important step in problem-solving, and creativity is an important part of teaching [39]. Ideation is one of the most direct representations of creativity, where the generation of ideas is a key process and is vital to problem-solving [20]. This is because having many ideas around a single topic promotes innovation and creates cognitive flexibility, which is critical when learning. In this project, idea generation may occur through generating hypotheses, designing experiments, or solving multiple alternatives to a problem [10], [45].

This STEAM perspective promotes the intersection of the arts with STEM, allowing for creative engagement within the science and technological domains [45]. Creativity is not only the end point of project processes but also the essence of the processes. There is a synergy between PBL and STEAM in evoking such creativity in students [12]. While PBL serves as the structure by which students can apply STEAM concepts to real projects, STEAM provides a rich multidisciplinary context where students are encouraged to think beyond traditional confines [12], [46], [47].

4. Challenges and Observations

Despite the favorable results, the research highlighted various challenges to applying STEAM-PBL. These included a dearth of resources, inadequate teacher training, and an aversion to change from existing teaching methods. The first stage is the driving question, the application of Project Based Learning (PBL), which confuses the teachers. Students faced a main hurdle in connecting the theory to the practice when developing their pond design and Instagram reels. Most students struggled to convert conceptual chemical ideas to the physical design of an effective *Daphnia sp*. pond. Equally problematic was a time management issue: students had to juggle the requirements of designing an intricate system while also learning video production techniques to make their reels. Compounding these hurdles were technical challenges, where learning to use video editing software and making sure video projects were visually comprehensible created additional challenges. These issues reflected the need for additional scaffolding around scientific design and multimedia content creation.

Regarding feedback, students liked the creativity and freedom of the project but said they could have used more structured guidance, especially during the experimental and design phases. Students marketed answers as they accomplished the tasks and used Instagram to communicate. Based on their answers, they use it to reflect on and improve their projects. One of the reactions is:

"*In my assessment, the utilization of Instagram reels as a medium for disseminating information and designing daphnia cultivation ponds represents a commendable initiative, as it serves as an educational resource for the broader community and is exceptionally well-suited for implementation in the era of 5.0, characterized by the seamless accessibility of information through various technological advancements. This approach enables individuals with limited knowledge to acquire novel insights regarding Daphnia Sp. and its cultivation ponds precisely and informally*" (Student 1, 20 Mei, 2023).

Some (notably two from the same major) stated that although the project allowed them to think critically and beyond the traditional boundaries of academia, they would have preferred more straightforward guidelines and step-by-step assistance to reduce their anxiety. A few students also emphasized that working in groups was rewarding yet difficult since coming up with ideas and establishing roles sometimes conflicted. I suspect that the Instagram reel format as a medium was well-received (the feedback from the students, who reported a high level of engagement and a sense of satisfaction in making an engaging product) may have had something to do with this.

Professional development around STEAM pedagogy and PBL is important to addressing these issues. Additionally, schools must foray into building the capabilities required to support STEAM activities. This means access to art supplies, technological tools, and locations encouraging creative collaboration. However, STEAM education must surmount logistical hurdles to be effectively implemented more broadly.

To advance knowledge and practice, additional studies are suggested to investigate the effects of long-term STEAM-PBL education on learners' character development and academic performance. In this sense, longitudinal studies can offer opportunities to understand how this type of learning persists over time for students and the articulation of new educational practices. Moreover, future studies can examine the effectiveness of STEAM-PBL education in varying subjects and educational levels, expanding on its applicability and influence on a broader scale.

CONCLUSION

In this study, STEAM (Science, Technology, Engineering, Arts, Mathematics) integrated with Project-Based Learning (PBL) was reflected as one approach to empowering curiosity and creativity in high school chemistry learning. Through this, you actively involve students in creating a *Daphnia sp.* As seen in the research, the use of interdisciplinary knowledge loved the skills critical in the learning of the 21st century, bubbling the construction of an experimental stimulation regarding the cultivation pond. The outcomes indicated a notable positive correlation between creativity and cognitive academic outcomes of the students, highlighting that STEAM-PBL has the potential to stimulate creative thinking and problem-solving skills. Although no significant relationship was observed between curiosity and cognitive outcomes, indicating that curiosity functions independently of academic performance in this study, further research is needed on promoting curiosity as a learning strategy.

While STEAM-PBL offers an engaging approach to education, several challenges emerged, including lack of funding, inadequate educator tools and training, and skepticism of divergent teaching methods. Identifying and addressing these barriers is necessary for scaling the adoption of STEAM education. Further research should also focus on the sustainable impact of STEAM-PBL along the different dimensions of student growth and whether STEAM-PBL could be adopted in different educational contexts. Educators who move past these barriers can build dynamic learning spaces that inspire creativity and curiosity to be utilized in the workforces of society.

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