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Research Article

CITIZEN SCIENCE PROJECT DESIGN FOR ECOLOGY COURSE: REDUCING POLLUTION CAUSED BY GOLD MINING

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Abstract

The article aims to provide an overview of designing a citizen science project in ecological learning, focusing on the case of gold mining pollution in the Batanghari River area. This research employed a qualitative method, non-interactive type with the approach used being concept analytical. The design of the citizen science project is conducted through a sequential cycle with its main components including: identifying the need or problem, determining if citizen science is the right approach, designing the project, building the community, managing the data, and evaluating the project. This project design illustrates an organized method of citizen science in ecological learning that is customized to the gold mining area. The contribution of participants is very important to emphasise at every activity in the project design, therefore the development of activities in this project refers to the logic model. The type of project relevant to the issue raised is to assess the potential or ecological status of the Batanghari River through the measurement of biological quality elements, physico-chemical elements, and hydromorphological quality elements, referring to the European Environment Agency standards. The design incorporates two distinct components: a collaborative project model and a framework based on research, both of which are arranged into mini-project activities. As a result, the project will contribute to improving students' skills in monitoring and collaborating with communities, as well as accommodating ecological learning activities intended as actions to help mitigate the problem of pollution due to gold mining in the Batanghari River.

Keywords: Batanghari River, Design Citizen Science Project, Ecology Learning, Gold Mining

INTRODUCTION

Increasing concerns about environmental degradation, particularly in stream around gold mining areas, provide a strong drive to innovate education on environmental conservation. It is evident based on observations from numerous cases that gold mining activities contribute significantly to the degradation of stream ecosystems and public health. The contamination of water and soil by harmful chemicals from gold mining may increase the risk of disease and other health problems for communities (Hou et al., 2023). Public participation is an essential element in preventing stream ecosystem degradation and the health problems associated with it (Jiménez et al., 2019). The public represents the immediate community that this problem will affect. One of the efforts that can be proposed is to involve the public in scientific activities to prevent worse conditions. Public engagement in scientific endeavors allows for greater breadth and depth of research, which in turn improves science literacy and public understanding of scientific issues. The involvement of the public is expected to increase their understanding of environmental issues and improve their environmental literacy.

The selection of the approach used to accommodate public involvement should be made with a great deal of consideration. The approach should have the ability to accommodate collaborative practice between professionals and the public. In addition, it is necessary to consider that science will be applied in practice by individuals or community groups of people who are not professional scientists. The approach chosen must have the power to characterise the extent of community application of science. A possible approach that can facilitate these needs is citizen science. This approach offers collaboration between professional scientists and the public, who meet in one activity (Roche et al., 2020). Citizen science brings both parties together to work on issues, including environmental issues, thereby strengthening conservation efforts through active participation and shared knowledge (Dunkley, 2017).

Bringing citizen science into the case of gold mining requires a number of important considerations. Gold mining operations, particularly in the stream ecosystem, present significant environmental challenges, including water pollution, habitat destruction, and changes in river flow pathways, as well as damage to stream ecosystems (Anggraini et al., 2019). Addressing these challenges requires the development of a comprehensive strategy that not only addresses the direct impacts of gold mining activities but also engages local communities in ongoing environmental monitoring and management. A noteworthy part of this engagement is how to integrate citizen science projects into learning (Berndt & Nitz, 2023), especially in contexts that highlight the impacts of gold mining activities. The integration is directed towards capturing opportunities to increase awareness and environmentally responsible actions among the public (Bruckermann et al., 2018), especially in areas that receive the most severe environmental impacts from gold mining activities.

The citizen science concept is an approach that has close ties with education, the environment, and society (Fraisl et al., 2022). The basic foundation that can be used as an argument to leverage citizen science in the education sector for environmental conservation activities is cooperation and collaboration. Through citizen science, people are invited to participate directly in scientific research and monitoring the quality of stream ecosystems. The activity not only expands the scope of monitoring the condition of the stream ecosystem, but also enriches the interaction between science and the public. Furthermore, this concept can be used as an approach to engage communities in understanding ecological principles. In this way, citizen science can be an effective way to foster a deeper understanding of ecology and encourage active community participation in environmental conservation efforts (Fraisl et al., 2022; Njue et al., 2019; Pocock et al., 2014). By actively engaging in citizen science activities, the public not only becomes connoisseurs of information but also participates as part of the solution to preserve the stream ecosystem.

Recent studies have highlighted the potential of citizen science as an approach to ecological learning. They illustrate that citizen science allows participants to contribute to meaningful scientific research flows while gaining hands-on experience with ecological concepts and research methodologies (Fraisl et al., 2022; Kobori et al., 2016; Roche et al., 2020). Another study has also been conducted specifically in the context of gold mining, where citizen science projects were used to monitor water quality, assess biodiversity, and track landscape change (Capdevila et al., 2020; Ceccaroni et al., 2023; Jollymore et al., 2017). The projects not only generate valuable data for scientific research, but also empower communities to advocate for sustainable environmental practices. In addition, these studies illustrate the importance of the concept of ecology in bridging the many variables that surround it.

Although citizen science has many benefits in environmental education and conservation, but the design of projects specifically is still needed to encourage the development and implementation of citizen science projects in the context of ecological education regarding stream environmental degradation associated with gold mining activities. An important point in development is to emphasise the need for an approach that adapts to the unique challenges and opportunities posed by stream ecosystems affected by gold mining activities. On the other hand, there is a perception that no one approach fits for every citizen science, so the stages of citizen science need to be adapted according to the context of the project itself (Fraisl et al., 2022)

The article provides an overview of the design of a citizen science project in ecological learning. The design process describes the creation of a structured approach to citizen science in ecology learning, specifically aligned to a gold mining area. The project will be used to enhance students' skills in monitoring and collaborating with the community through shared observation activities. The design of the citizen science project was carried out by taking into consideration the results of previous research, which is to improve problem-solving skills (Alfaro-Ponce et al., 2023; Shah & Martinez, 2016), and environmental awareness derived from environmental literacy for students (Meschini et al., 2021; Weisberg et al., 2023), and enhance sustainability literacy for communities (Hovis et al., 2020; López-Iñesta et al., 2021) that will face the direct consequences of ecological degradation due to gold mining activities. In addition, this design will provide ecological learning activities that apply scientific knowledge to discover ecological concepts in a real-world context through the integration of citizen science projects that can support competency improvement in accordance with the expectations of students around the Batanghari River area that identified by previous research (Susbiyanto et al., 2024).

Bridging the gap between scientific research and public engagement, the development of this citizen science project design is also intended to prepare a more resilient community capable of advocating for sustainable environmental practices and mitigating the threats posed by gold mining activities around the Batanghari River area. Furthermore, the design is developed to accommodate ecological learning activities that are intended as actions to help unravel the pollution problems caused by gold mining activities in the Batanghari River. Referring to the research results obtained from the Research and Development Centre for Quality and Laboratories by the Ministry of Environment and Forestry of the Republic of Indonesia, the conditions illustrate that the Batanghari River currently has mercury distribution in both river water and river sediments (Ratnaningsih et al., 2019). Mercury in river water fluctuates in the range of <0.0005- 0.0645 mg/L, while in river sediments it is detected in the range of 0.01 - 0.42 mg/kg. The presence of mercury in river water and river sediment needs attention so that the source of pollutants from artisanal gold mining can be prevented further so that the negative impact of mercury pollution can be minimized.

METHODOLOGY

This research applied a qualitative method of non-interactive type, which is a research on concepts through a document analysis (McMillan & Schumacher, 2014). The approach used is analytical concept, where this study tries to explain the meaning or interpretation of a concept by describing or explaining the essential or generic significance of a concept, the different interpretations and the actual use of a concept (Cohen et al., 2018). So in this research, it is done by identifying, analysing and then synthesising the available data to provide an understanding of the concept under study to determine the actual use of a concept (McMillan & Schumacher, 2014). In this context, the concept being researched is a concept related to the design of citizen science projects for ecology courses, especially in the case of river pollution caused by gold mining.

The citizen science project design in this article was prepared using qualified literature sources and adjusted to the needs and characteristics of the problem. The preparation of the citizen science project design adapts the references discussed by Fraisl et al. (2022) who recommend a 6-stage cycle for designing citizen science projects, especially in environmental and ecological studies. The stages of the cycle sequence for designing citizen science projects are presented in Figure 1:

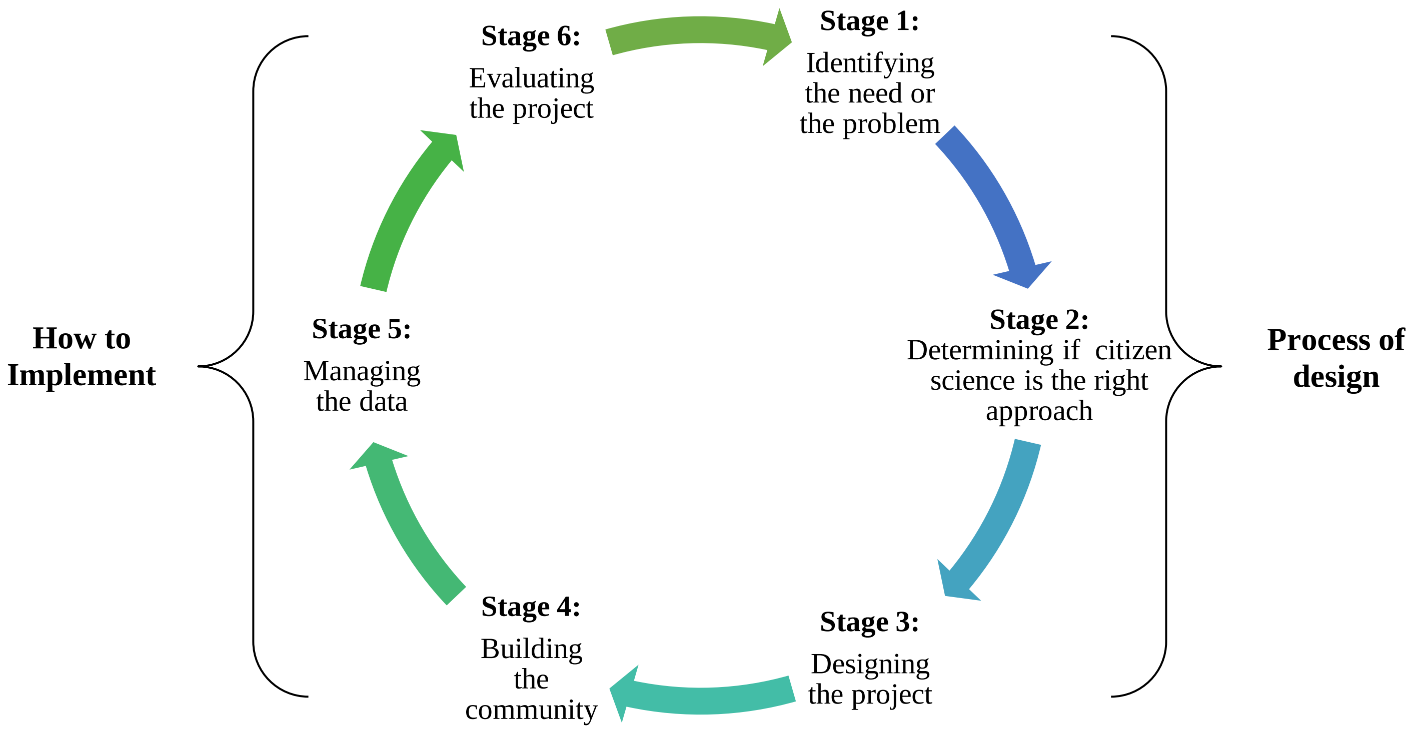

Figure 1. Stages of designing citizen science project in ecology (Fraisl et al., 2022)

The cycle presented in figure 1, illustrates two main groups at the stage of developing a citizen science project design: the process of design section and the how to implement section. In the process of the design section, there are three stages that need to be carried out to eventually produce the design of the project. Meanwhile, in the section on how to implement, there are three stages that need to be considered. The core of those three stages is how the project will be implemented. The description related to the how-to-implement part of this project, starting from building a community, processing data, up to evaluation, have been arranged in the design of the project in stage 3. Although the how-to-implement part is part of the "field action," which is implemented after the project design has already been completed, the implementation scenario is already well-described in the project design.

The design of the project also paid attention to the concepts that will be explored in learning ecology. The project will primarily focus on watershed conservation as a case study, highlighting the ecological ideas that are highly relevant to the topic at hand. Watersheds serve as both water sources and intricate ecological systems, characterized by abundant biodiversity and vital hydrological roles. Strengthening the concept of ecology in this project was conducted by reviewing the collaborative approach between students and the community. The involvement of participants in watershed ecosystem quality monitoring activities will provide a deeper understanding of the interactions between humans, flora, fauna, and environmental factors that affect the balance of river ecosystems. Monitoring activities are conducted using the "Water Framework Directive" (WFD), developed and used by the European Environment Agency (EEA) for river water conservation. This reference provides clear information on how to assess the potential or ecological status of waters through the measurement of biological quality elements, physical-chemical elements, and hydromorphological quality elements (EEA, 2018). The project developed in this article adopts the three-element measurement implemented by the EEA, which aims to obtain information on the level of pollution and habitat degradation around gold mining areas. The data collected from the measurement activities can be used as a reference to propose ideas, suggestions, or actions that can be taken to prevent degradation of the river due to gold mining. Ideas, suggestions, or actions that are obtained from the implementation of citizen science projects will be expected to produce products that can be claimed as the result of this project.

The design also concerns the two groups of participants that will be involved, which are the students and the community. Both will get different outcomes, so the intensity of the involvement of each group will adjust to the outcome. During the construction process, the intensity of participant involvement is determined through the use of the citizen science project model. Due to the fact that the citizen science project design offers a spectrum of participation intensity and offers various types of activities, the determination of the project model used refers to "public participation in scientific research" (Shirk et al., 2015). The logic model adopted in this design leads to the use of two different models, each of which can be used to determine the level of intensity of involvement of two groups of participants in the project. The model used here will provide more opportunities, especially for students, to obtain outputs and outcomes, as well as encourage optimal public involvement. The use of two separate models will make it easier to determine the type of activity for each participant (Bruckermann et al., 2018). In the present context, the appropriate engagement model for students is a collaborative project, and the appropriate engagement model for the community is a contributory project.

The citizen science project developed in ecology learning in this article also strives to increase student involvement in solving various problems that are close to their lives. The implementation of this certainly pays attention to collaborative projects as a model of engagement that is used. In order to maximise ecology learning activities embedded in citizen projects, a framework is needed to support the elements it contains. The selection of a framework relevant to the model used is an important part of the success of the learning activities developed (Spires et al., 2016). The framework chosen in this project is a research-based framework adopted from Ballard et al. (2017). The use of the framework aims to help students experience learning activities that are not only about collecting data through citizen science activities but also how to improve students' analytical and critical skills through the process of inquiry, interpretation, reflection, and application of scientific knowledge to discover ecological concepts in a real context (Harris & Ballard, 2018). The way to optimise this integration is to consider how to design and facilitate these activities to provide meaningful learning by involving students in collaboration. One of the solutions chosen to link the research-based framework with the collaborative project model is to provide a particular space for students to develop mini-projects that they will work on. These activities allow students to work together, collaborate, and share their diverse knowledge and skills (both with their peers and with the public), thereby increasing the quality and innovation of each project they undertake. Furthermore, the research-based framework provides a strong methodological foundation, ensuring that the project is not only innovative but also has a solid scientific foundation. Hence, the integration of both elements into the mini-project not only enriches students' learning experience but also enhances the relevance and practical application of the knowledge they acquired during the learning process. This activity will create an environment favourable to active learning and the application of theory to practice, which are critical aspects of higher education recently.

RESULTS AND DISCUSSIONS

This section provides an overview of the six-stage cycle in designing citizen science projects (Figure 1) that contribute to the ecological issue (Fraisl et al., 2022). The six-stage cycle in designing citizen science projects proposed by Fraisl et al. (2022) used in this research has been analysed through several relevant documents. The main reason for its selection was determined by the adoption of several leading citizen science projects in Europe and America, including the ILTER community, Conserving biodiversity Marine Species in the Barcelona Metropolitan Area project (URBAMAR), B-WaterSmart.eu dan The Western Redcedar Dieback Map (WRDM) project (Bergami et al., 2023; Fraisl et al., 2022). The six-stage cycle has also been successfully applied to various research fields, which in turn has further contributed to the development of best practices and new approaches in ecological and environmental sciences (Fraisl et al., 2022). An example is in determining the contributions of citizen science to SDG monitoring and reporting on marine plastics (Fraisl et al., 2023). Based on the results of the analysis, this study adopted the full six-stage cycle for the design of the citizen science project, particularly in the case of gold mine waste pollution in watersheds. The use of the six-stage cycle in this research will provide convenience in conducting a systematic mapping of all stages of the design, then characterising each stage of the design based on the contributions of the participants involved, making it easier to achieve the objectives of the project. Each stage of the design is interconnected, and one stage does not have to end before another stage begins (Fraisl et al., 2022). It means that all stages and steps can be revisited along the cycle. This ensures that it is easier to incorporate change factors, lessons learned, and feedback from participants. The details of the stages are explained in the next section.

Stage 1. Identifying the need or the problem

The main focus of the issues highlighted in this project is closely related to gold mining pollution in the Batanghari River. Issues discussed include the quality of the Batanghari River ecosystem and community participation in the management of natural resources and the environment.

The project was designed to develop and implement an effective Citizen Science program that can be used to monitor and reduce the level of gold mining waste pollution, as well as support ecosystem conservation efforts in the Batanghari watershed by involving the participation of students and the community. A project relevant to the case presented in this project is assessing the potential or ecological status of waters through the measurement of biological quality elements, physical-chemical elements, and hydromorphological quality elements (EEA, 2018). Measurement activities seek to collect information about the quality of river ecosystems through data. Furthermore, participants will be directed to find solutions in accordance with the data obtained and then be guided to the next issue, specifically how to manage natural resources and the environment in accordance with the information that has been collected. The participants who will be involved in this project are students and the public. Based on the logic model (Shirk et al., 2015) used in the design of this citizen science project, student participation is more dominant at every stage of project activities. Students take on roles to help refine the project design, collect data, analyse data, and disseminate findings. Meanwhile, the community will be involved in the data collection process in the field. The number of student contributions to citizen projects both in field activities and in the process of refining project design constitutes involvement in the collaborative projects model, while public participation in data collection activities with students is a way of involvement in the contributory projects model.

The wide scope of the intensity spectrum of the problem presented initiated determining the project boundaries for the citizen science design that was compiled. The determination of project boundaries is conducted to effectively achieve the objectives of the citizen science project. Determining the project boundaries will help to focus the resources and efforts of the citizen science project on the most critical aspects and the most feasible aspects (US, 2022). The boundaries of this project begin with determining the location of the project, where the location selection is not far from gold mining activities. The location selection is also based on the level of pollution, accessibility, and local community involvement. Then, to organise the data collection schedule, it can be done periodically according to the condition of the river water discharge. On the other hand, the problem of gold mine waste pollution basically has many dimensions (Bonney et al., 2020), but the project is only designed to assess the potential or status of aquatic ecology, where the focus is to measure the quality of the Batanghari river ecosystem and then involve community participation in natural resource and environmental management. The project will rely on the active participation of students and local communities, utilising technologies and methodologies that are easy to use by ordinary people and have reliability in the context of citizen science research (Carlson & Cohen, 2018). Another stakeholder that will be involved in this project is the local government in charge of environmental issues, which is *Badan Pengendalian Dampak Lingkungan Daerah* (BAPEDALDA).

Stage 2. Determining if citizen science is the right approach

The second stage of the project design process is to determine whether citizen science is an appropriate approach to addressing the problem. This involves identifying the problems that have been outlined in the first stage. The objective is to find out whether using a citizen science approach will help participants achieve the expected result, which is to overcome the proposed problem. In addition, whether using a citizen science approach will provide benefits for participants to fulfil their needs or develop new skills and expertise (Van Brussel & Huyse, 2019). As long as both conditions are met, then a citizen science approach is likely to be appropriate for the project (Tweddle et al., 2012).

Based on the previous argument, the citizen science approach is an appropriate approach to be applied to this project. The main point of departure is the participation of students and the public in the project design. Where the participants are directed to find solutions to the problems posed. The public is the operator in the community as well as the actor who will directly receive the negative impacts caused by gold mining activities. While the position of students as agents or operators who bring projects to collaborate with the public to find solutions to overcome the problems that have emerged in order to minimise the negative impact. Students will transfer their knowledge and skills to the community directly through activities that have been designed in the project.

Involving the public in the project gradually provides an opportunity to increase public awareness of the problem being addressed, besides strengthening the community's engagement and understanding of the science and related issues. This approach also accelerates the process of collecting broad and diverse data, which in turn improves the quality and relevance of the results obtained (Capdevila et al., 2020). Furthermore, citizen science provides opportunities for students and the public to learn and develop new skills, such as data analysis, scientific observation, and scientific communication, which will be useful not only for this project but also for building personal capacity. Therefore, the citizen science approach not only fulfils the objectives of the project in addressing the problem, but also provides significant added value to individual and community capacity building.

Stage 3. Designing the project

The third stage is the core part of the citizen science project design phase. This stage contains a project description consisting of a series activities and also important information related to the next stage. The development of design project adapts Shirk's logic model, presented in Figure 2. The design refers to the main point, which is the direct link between the potential outcome of citizen science with the activities that were provided (input) and the experience of participants (output) (Lorke et al., 2021). The contribution of participants is very important to emphasise at every stage in the project design (Bruckermann et al., 2018).

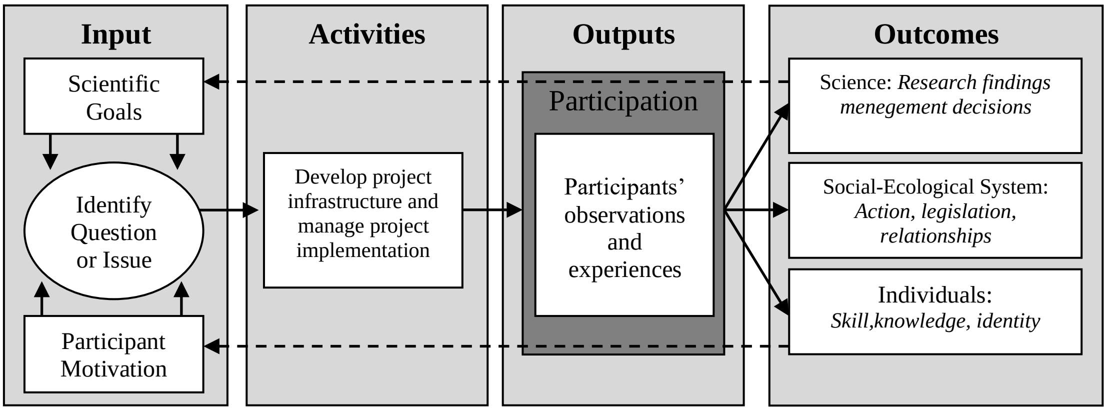

Figure 2. Citizen science logic model Lorke et al. (2021), adapted from Shirk et al. (2015)

The logic model in Figure 2 highlights four main parts: inputs, activities, outputs, and outcomes. Overall, the model illustrates how citizen science projects can transform inputs into structured activities that produce specific outputs, eventually influencing outcomes in scientific, social-ecological, and individual level. The employment of logic models is essential in planning and evaluating citizen science projects. They provide a clear framework for linking inputs and activities to desired outputs and broader outcomes, ensuring that citizen science initiatives can deliver significant scientific benefits as well as positive impacts for the communities and individuals involved (Lorke et al., 2021).

Designing citizen science project in Ecology (Figure 3) adapts the logic model with regard to the six-stage cycle. In general, the design visualises the relationship between four main sections: available resources (input), the activities carried out (activities), the output produced, and the expected outcome. Each section contains project activities that represent the actions to be performed by the participants in the project. The positioning of each project activity in each section is adjusted to the characteristics of the logic model and also the actions of the participants in the project. The "input" section contains project activities to promote problem-orientation by participants. The "activities" and "outputs" sections contain project activities that intersect with each other. The "activities" section is part of developing project infrastructure and managing project implementation, intended to produce mini-projects that will be implemented in the next section. So the project activities involved in this section are project activities 2, 3, and 4, which are activities to generate information to compile mini-projects. The "output" section is a place for participants to make observations and multiply their experiences accordingly. The project activities involved are project activities 3, 4, and 5, which are activities that provide experience and skills for all participants. The final part, "outcome," is the expected result or output of the citizen science project, which reflects the impact and contribution of the project implementation. In order to understand the description of the project activities in the design of the citizen science project adapted by the logic model, a detailed explanation is presented in the next section.

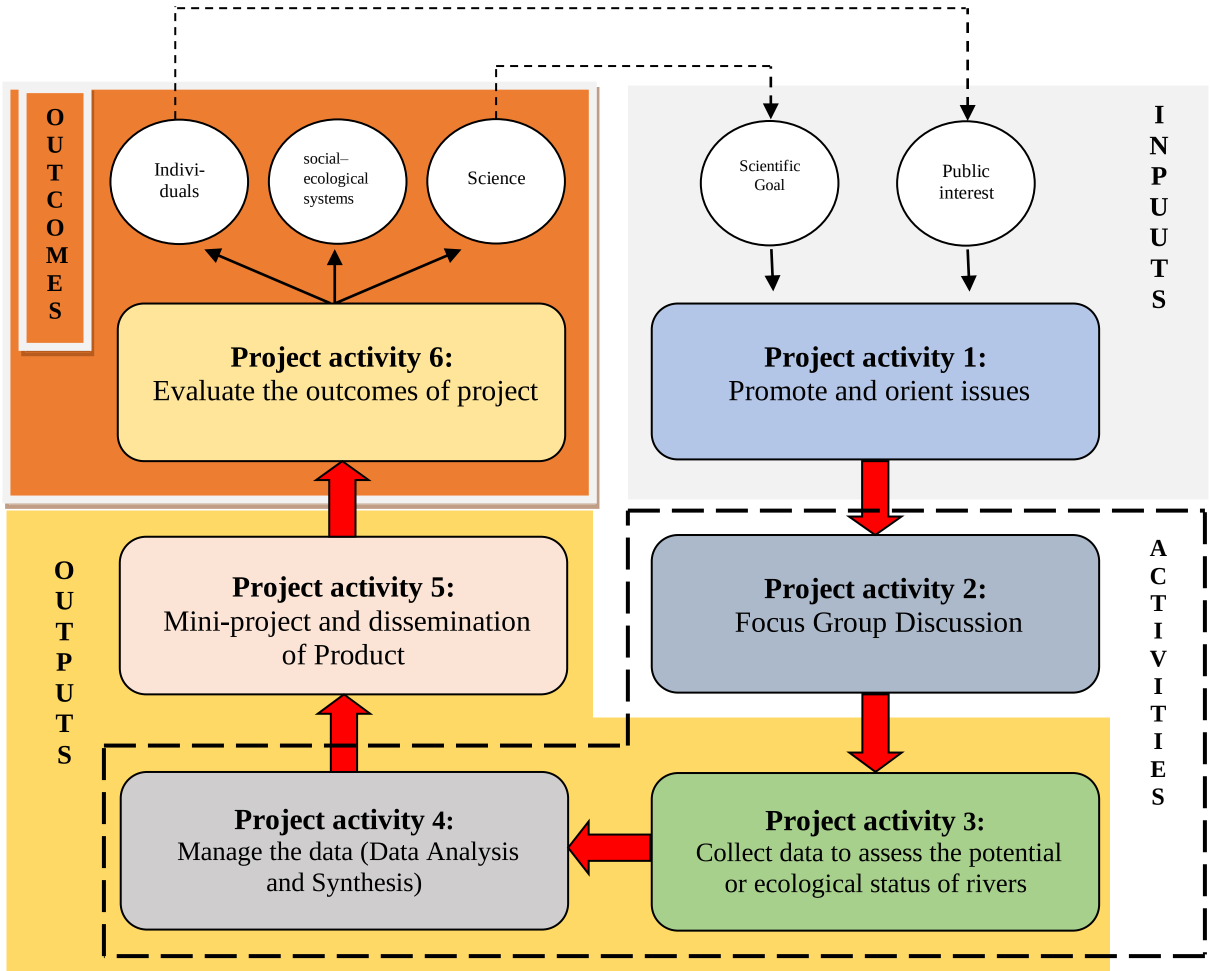

Figure 3. Designing citizen science project in ecology with logic model (adapted from Lorke et al. [2021], and Shirk et al. [2015])

a. Promote and orient issue

The initial part of the project design overview presented in Figure 3 begins with determining the input of the project, which includes setting scientific goals to be achieved and determining various aspects related to the interests of participants in the project. The determination of both elements is adjusted to the focus of the main problem, which is the pollution of gold mining waste in the Batanghari watershed. The process of determining both elements did not involve the participants at all. The main problem in the project was also used to develop the material to be delivered to students.

Subsequently, activities in the citizen science project will begin with student activities that orientate and promote gold mining pollution problems that are relevant to their lives and society. This stage attempts to stimulate students by introducing and providing an understanding of the problem at hand, including its causes, impacts, and relevance. Students are encouraged to comprehend the definitions and fundamental concepts of gold mining pollution, including the types of pollutants produced and their mechanisms in destruction the Batanghari River ecosystem. Additionally, students need to know how the gold mining process may cause pollution, starting from the stages of exploration, extraction, to gold ore processing or amalgamation. Students are encouraged to explore the techniques and methods of gold extraction used by miners around the Batanghari River, as well as the potential environmental impacts caused by each method applied by miners, such as habitat destruction, decreased water quality, and loss of biodiversity.

The learning presented attempts to encourage students to understand the impact of pollution on surrounding communities, such as loss of livelihoods, decreased quality of life, and health risks posed by water pollution. Furthermore, students are directed to relate the relevance of the problem to their lives and society, which includes health and quality of life, by realising that gold mining pollution contributes directly to the health and quality of life of surrounding communities, both through the consumption of polluted water, and through the food chain (Ceccaroni et al., 2023). Then students try to relate the community's dependence on natural resources by recognising how the sustainability and availability of natural resources, such as clean water and fish resources, depend on the quality and conservation of healthy river ecosystems. Lastly, students relate the relevance of the problem to the context of social and environmental responsibility by acknowledging as part of the community, students have a moral and social responsibility to preserve the environment and contribute to efforts to solve the problem of gold mining pollution (Berndt & Nitz, 2023). With a strong basic knowledge of the problem of gold mining pollution, students are expected to take constructive action and be involved in promoting solutions through mini-projects planned in the next activity.

b. Focus Group Discussion

The second activity of the project is a Focus Group Discussion (FGD). This activity sought to enhance the students' understanding of the issues being discussed by presenting guest speakers who came from government institutions responsible for environmental issues. FGDs facilitate direct dialogue and information exchange between experienced environmental experts in this case it is BAPEDALDA. Furthermore, focus group discussions will encourage a better understanding of the problem presented (Cigarini et al., 2022), which is the pollution of the Batanghari watershed caused by gold mining waste. The discussion may also open up personal experiences and clarify the impact of the problem on the environment and public health (Santos et al., 2019). Additionally, it will also provide direction for students to focus on the problem and formulate mitigation strategies and solutions that can be effectively implemented through the mini-projects they will be working on. Key themes can be identified from the discussions conducted in the focus, which will bring up many ideas that can be applied to student projects (Kenneally, 2021). By involving relevant stakeholders, the generated solutions are expected to be sustainable and can support efforts to reduce gold mining waste pollution and maintain the sustainability of the river ecosystem. After obtaining various information and knowledge from FGD activities, students are directed to develop a rough design of the mini-project they will work on.

c. Collect data to assess the potential or ecological status of rivers

The third activity of the project is collect data to assess the potential or ecological status of rivers. Data collection is the primary goal of most citizen science projects (CitizenScience.gov, 2023). The success of a citizen science project can be determined by agreeing on metrics to measure success, and to measure potential current or future impacts (Fraisl et al., 2022). To conduct a series of measurements, data is needed as a source of information. Data collection activities in citizen science projects make it possible to obtain real-time and temporal data, especially in studies that require monitoring changes over time and a wide range (Njue et al., 2019). Data collection is undertaken by students and the community using a guide which has been compiled. The data obtained will be used to assess the potential or ecological status of the river around the gold mining area. Assess the potential or ecological status of rivers conducted in the present project adopted the EEA's "Water Framework Directive". The main reason for adopting the WFD for this citizens' project is having a proven measurement method, especially for evaluating the ecological status of waters, hence lending credibility and relevance to the data and information collected. Another reason is that it can strengthen local actions and environmental management policies based on scientific evidence, therefore allowing the improvement of the quality of river ecosystems and the maintenance of environmental sustainability around gold mining areas.

The WFD provides a standardised and structured methodology that assesses three primary elements: biological quality elements, physical-chemical elements and hydromorphological quality elements (EEA, 2018). Measuring biological quality elements is conducted by assessing groups of organisms that reflect the ecological condition of waters by identifying macroinvertebrates, which are intended to see their responsiveness to changes in water quality and the environment (EEA, 2018; Lindegarth et al., 2016). Measuring physic-chemical elements within the WFD framework is undertaken by analysing various physical and chemical parameters of water including: temperature, pH, clarity, dissolved oxygen, nutrients (nitrogen and phosphorus) and heavy metal mercury (EEA, 2018). Measuring hydromorphological quality elements is conducted by evaluating aspects such as river morphology, water flow dynamics, and the physical condition of aquatic habitats, where the assessment includes an evaluation of the structure of the river or water body, including channel shape, bottom substrate, and the presence of natural features. The overall assessment provides a comprehensive picture of the ecological status of the water body (EEA, 2018). Measurement results are integrated to determine whether the water body fulfils the quality standards set by the WFD, which strive to achieve or maintain a 'good' status or higher, based on established criteria.

d. Analysis and synthesis data

The fourth activity of the project is data analysis and synthesis, the essential part after data collection. The data obtained will be analysed in depth by the students, including by testing hypotheses related to water conditions and the factors that affect them. This analysis involves the use of statistical methods and modelling to acquire a better understanding of the problem being addressed. Furthermore, the data is also used to conduct a robust assessment of the risk of various possible solutions. The data analysis is performed by reviewing several key points including water quality, environmental sustainability, social impacts, and risk assessment, which are further used to assist in selecting the most effective and sustainable solution for the environment and surrounding communities (Fischer et al., 2021). The results of the analyses and risk assessment served as the basic foundation for planning the solution actions through the Mini-Project. The mini-projects include specific measures such as habitat rehabilitation, water resource management, community awareness campaigns, and other forms of projects. Carefully analysed data can help in designing targeted solution actions that will have a significant positive impact in maintaining water quality and the ecosystem in general (Sprinks et al., 2022). The adoption of a holistic, data-driven approach in the Citizen Science project is likely to make a meaningful contribution to the sustainability of the river environment to address the problems found in the area of study (De Sherbinin et al., 2021).

e. Mini-projects and dissemination

Mini-projects provide activities that are relevant to the framework employed by this project. The main underlying reference is the research-based framework of Ballard et al. (2017). The concept applied in the project draws on three interconnected core elements in accordance with the results applied by Harris & Ballard (2018). The first part is the most fundamental part where students develop an understanding of environmental science content and enquiry practices. This section will develop students' deeper understanding of the ecosystem in which they are implementing the project. Students learn how to collect and analyse data, evaluate data quality, draw conclusions, and communicate findings through writing and presentations. The second part deals with how students identify themselves as experts and develop personalised roles in scientific work. Here, students will act as experts who will collaborate with their peers and the community in collecting data or organising their project or presentation. Finally, students utilise their citizen science experience to create change (both large-scale and small-scale) that they can spread in their lives or communities. Students may realise these experiences in various ways, starting with earning the confidence to share their ideas, to advocating for changes in the management of natural resources and the environment to the community. The last part is the right space to position the mini-project as a means of actualising students' ideas and notion that present solutions to the problems they have found in the field.

Project-based inquiry is an approach that can be employed in the Mini-Project activities within this project. Educational activities implementing project-based inquiry emphasize active learning through projects designed to address real-world problems (Kolodner et al., 2016). Project-based inquiry is rooted in problem-based learning (Boss & Krauss, 2018; Spires et al., 2019), built upon a strong orientation towards real-world issues. The inquiry-based approach allows a range of tools and technological resources to be utilized by students to explore and create new knowledge by answering intriguing questions (Spires et al., 2021). The Project-based inquiry approach provides opportunities for students to develop and implement strategies to seek answers or solutions to the issues they encounter. Students can also utilize various resources and technologies to address the problems they are dealing with. It also gives students the opportunity to collaborate with peers and the community, as well as the chance to communicate their findings to a broader audience.

The project-based inquiry approach implemented in the project refers to Kolodner et al., (2015), which is an approach to learning science content and skills through direct experience by undertaking design challenges. It will begin by presenting scenarios and problems to students, challenging them to design devices or projects to solve these problems. In this context, the problems addressed by students align with real-world conditions in the field, supported by data obtained from analysis and synthesis. The scenarios and problems in the design units are carefully selected to guide students into investigating specific scientific concepts, and the problem-solving process is meticulously structured using specific scientific reasoning skills (Kolodner et al., 2016). Students engaged in design challenges have the opportunity to conduct investigations. Investigative activities can be conducted at any time as needed during the design process (Yata et al., 2020).

The learning design in the project-based inquiry approach used by Kolodner et al. (2015) consists of two main elements. Each element represents its respective components. The first element is "design/redesign," while the subsequent element is "investigate and explore." The interaction of the project-based inquiry elements along with their components is presented in Figure 4. The interaction and cycle that occur within each element in Figure 4 illustrate that the transition from "design/redesign" to "investigate and explore" is marked by an arrow labeled "need to know", while the transition from "investigate and explore" back to "design/redesign" is represented by an arrow labeled "need to do". This mode of thought is useful in considering the relevance of feedback loops between the ongoing scientific processes (Yata et al., 2020). Referring to the 6-stage cycle in Figure 1, the portion utilized by the mini-project to be implemented by students in their activities emphasizes the "need to do" pathway leading to the "design/redesign" element. Meanwhile, the "need to know" pathway leading to the "investigate and explore" process has been undertaken by the students in Activity 1 (Promote and orient issues), Activity 2 (Focus Group Discussion), Activity 3 (Collect data), and Activity 4 (Manage the data). The "need to do" components applied by the students for their mini-project adapt existing components but are tailored to the context of this project. Thus, these components are simplified into three main components: Design, Construct, and Apply and Share.

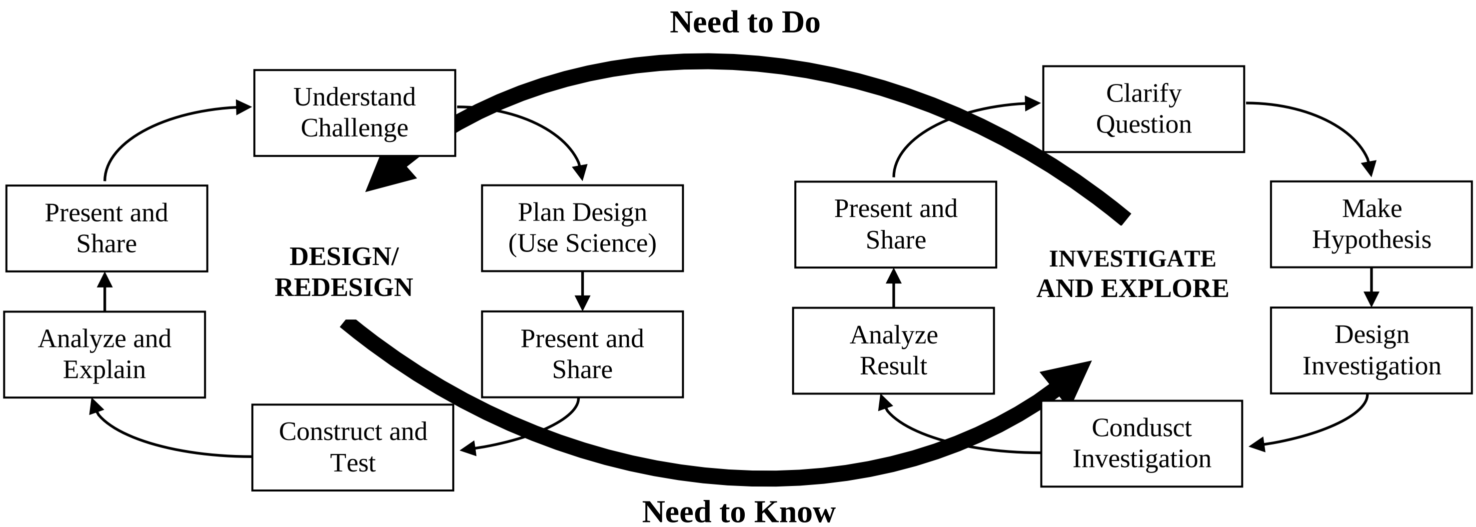

Figure 4. Learning design in the project-based inquiry approach (Kolodner et al., 2015)

The processes of these components require support from relevant knowledge, principles, theories, and skills according to associated factors such as materials, models, and technologies used. Therefore, adequate knowledge, skills, and thinking styles are needed to accommodate these aspects. Knowledge and thinking styles in this context directly relate to understanding theories and laws within science, the application of technology and laboratory skills, as well as work management (manage the work). The output of the mini-project implemented by the students will be claimed as a product of the citizen science project. The framework of the students' mini-project is simply presented in Figure 5.

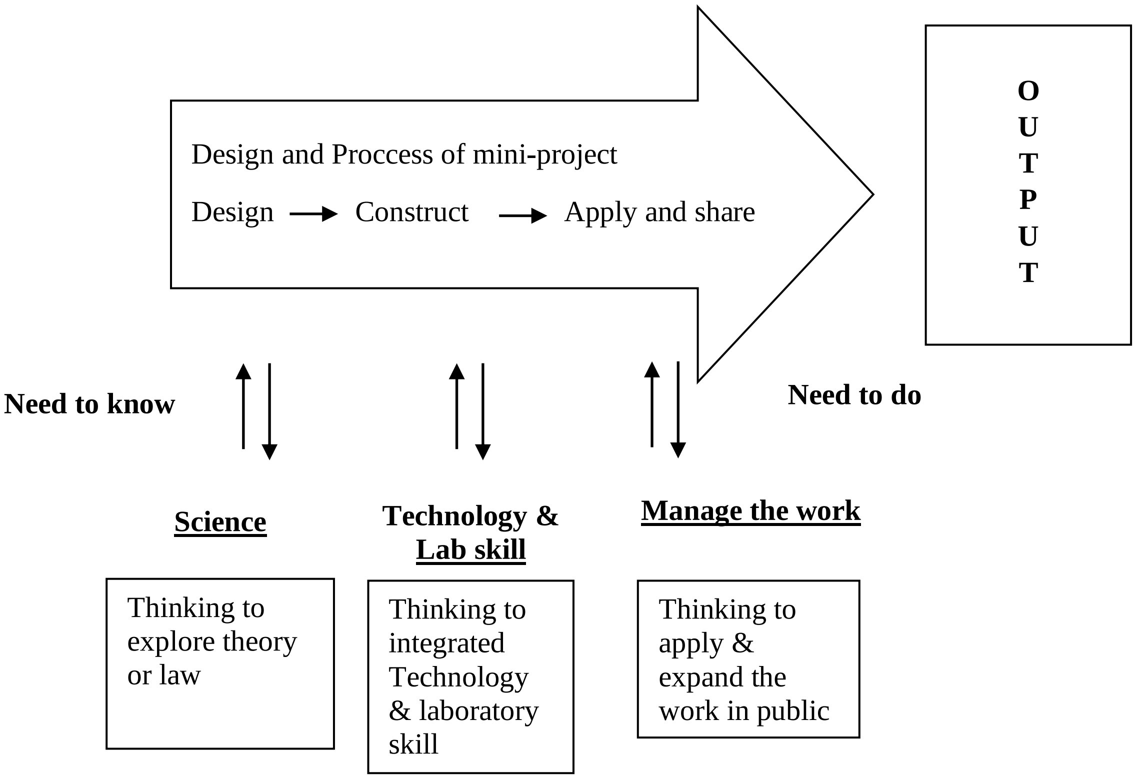

Figure 5. Student mini-project framework in Designing citizen science project for ecology

The mini-projects implemented by students in the Citizen Science project will yield several significant achievements. One simple example is the increased public awareness of the importance of preserving river ecosystems, which they gain through educational campaigns and socialization. Additionally, the outcomes of the mini-projects will be documented in the form of scientific reports to be published in relevant scientific journals, thus accessible to experts and environmental enthusiasts. Furthermore, these results will also be disseminated through social media, seminars, and workshops to reach a broader audience interested and involved in environmental conservation efforts. Therefore, the mini-projects carried out by students in this Citizen Science project not only provide local benefits in the form of concrete solutions but also contribute to enhancing public knowledge and serve as a source of inspiration and learning for various parties concerned with the sustainability of river environments.

f. Evaluate the outcomes of project

The sixth part of the Citizen Science project activities is the evaluation of the project's outcomes. This evaluation is a part of the formative evaluation process conducted without involving the participants directly. The purpose of evaluating this project is to understand the extent to which the project achieves its predetermined goals, whether related to increasing public awareness, enhancing scientific knowledge, or implementing concrete solutions to address environmental issues. The evaluation of the Citizen Science project is expected to reveal a number of significant outcomes based on three main aspects: socio-ecological systems, science, and individuals (Schaefer et al., 2021).

In terms of the socio-ecological system aspect, this project aims to have a positive impact by strengthening collective awareness and responsibility towards the environment, particularly concerning river pollution due to gold mining. Collaboration among various stakeholders, including students, environmental activists, and local communities, is expected to foster innovative and sustainable solutions in river environmental management. It will create healthier and more sustainable environmental conditions for the river ecosystem and the communities depending on it. Regarding the scientific aspect, the project is anticipated to make a valuable contribution in enhancing public understanding of the impacts of gold mining on water quality and river environments. The data collected and the analyses conducted pave the way for further research and the development of more effective technical solutions in combating river pollution. On the aspect of participation, the involvement of students and the community in this project provides valuable learning experiences and practical applications of science for students in a real-world context (Berndt & Nitz, 2023). Students not only develop practical skills but also become active agents of change in preserving environmental sustainability. On the other hand, the community participants are also expected to experience direct benefits in the form of increased awareness and well-being related to the improvement of their environmental quality.

Stage 4. Building the community

At this stage, it is crucial to consider effective ways to organize the involvement of students and the community. In the project design prepared, community engagement is fostered through direct meetings. This is to explicitly ensure the role of citizen science facilitators (lecturer and students) to interact face to face and create an emotional connection to the community, and also assist in ensuring the success of the project implementation. Students will be directed to master skills and expertise in facilitating projects, communication, as well as public engagement or access to the community. Additionally, the lecturer as facilitators in this research can also help foster relationships among all involved parties, creating stronger collaborations. After involving students and the community, the sustainability of participation in the project is also determined by how well-designed strategies are implemented (Özden & Velibeyoğlu, 2023). Engagement can also vary as external factors can influence the project's implementation in the field (Berndt & Nitz, 2023).

Stage 5. Managing the data

This stage highlights the systematic processes and steps related to data management, starting from planning, data collection, to data assurance. The planning step is essential to prepare various elements needed in the data management plan. This part is closely related to the project design phase that must be prepared, including considering requirements such as regulations regarding data privacy and ownership, as well as policies relevant to data access and sharing (Fraisl et al., 2022). Moreover, it is crucial to define ethical project practices, such as how to link participant contributions to maintaining data privacy and documenting it through the tools used, including which data will be shared and how to share it (De Sherbinin et al., 2021). In the planning stage, it is also important to make final decisions regarding the types of observations needed to achieve the project's goals and objectives. Examples of observation types include images, videos, water samples, sensor data, and interpretative data (Pocock et al., 2014). Additionally, in the planning step, it is essential to devise data processing methods, sample collection designs, sample collection training, and evaluations to review evolving project needs (Fraisl et al., 2022). Furthermore, it is important to clarify which data will be collected and how to visualize this data to facilitate the interpretation of results, for example, through graphs, summary tables, or maps (De Sherbinin et al., 2021). The project team should monitor findings throughout the project and share these findings with participants and other groups, while simultaneously encouraging them to support the evaluation of these findings and communicate them to the public (Sprinks et al., 2022).

The data collection step refers to the type of information needed to achieve the project's objectives. In ecological and environmentally-contributive projects, directing the collection of data often involves using various specialized equipment, adhering to standard protocols, or through a combination of specific methods (Balázs et al., 2021). When collecting observational data, the use of equipment must be carefully considered based on the capabilities of the participants involved, as well as the ease of accessing technology from the instruments used. Therefore, data collection training can be provided with the aim to ensure that participants have all the information they need to assist in generating the required data (Margherita, 2021). In this section, it is also important to consider the potential use of data for future needs. Moreover, it is crucial to decide on the types of observations and additional information that will be collected (Fraisl et al., 2022).

The data assurance step is essential to ensure the quality of data produced as part of the project. Data quality is closely related to the relevance of the data to its objectives, meaning that the data is sufficiently accurate for its intended use (Downs et al., 2021). Data quality can be assured through quality assurance processes, which are implemented before and during data collection, and quality control processes, which are conducted after data collection (Kosmala et al., 2016). The quality assurance and quality control processes need to be defined in accordance with the project's objectives, goals, and scale. For example, quality assurance processes can be undertaken by providing training to participants or developing standard protocols for data collection (Downs et al., 2021). Meanwhile, quality control processes can be performed by identifying outliers or checking the data submitted by participants. Checking the data quality for small-scale projects can be done by involving experts, but for larger projects involving thousands of participants, engaging experts can be quite challenging (Fritz et al., 2019).

Stage 6. Evaluating the project

Evaluation is a crucial step in any project, including citizen science. Project evaluation is a pivotal stage in the citizen science project design cycle in the field of ecology, as detailed by Fraisl et al. (2022). At this stage, comprehensive evaluation is conducted to measure the effectiveness and impact achieved. The evaluation process may assist in determining the degree to which the project has achieved its pre-established objectives (Schaefer et al., 2021). It is essential to assess whether the project has progressed as planned and delivered the expected outcomes (Bruckermann et al., 2018). Furthermore, through evaluation, areas needing improvement or further development in the future can be identified. This allows for adjustments to strategies, methods, or solution implementations to make the project more effective in the future (Bruckermann et al., 2018; Roche et al., 2020).

Evaluation is a way to verify if the solutions implemented in the project are genuinely effective in addressing the present issues. Through evaluating the effects of the implemented solutions, it can be ensured that the project makes a positive contribution to solving the environmental problems (Fraisl et al., 2022). Evaluation is also crucial for maintaining transparency and accountability of the project to the public and stakeholders (Özden & Velibeyoğlu, 2023). With open and transparent evaluation, the project can gain greater trust and support from all parties involved.

The evaluation process also provides an opportunity to gain valuable insights from the experiences gained during project implementation. Analyzing the successes, challenges, and lessons learned during the project implementation can encourage improvements and more appropriate strategies for future projects (Roche et al., 2020). Thus, in the end, the evaluation process offers opportunities to generate recommendations for adjustments to the project design, data collection methods, and community management strategies (Fraisl et al., 2022). This ensures that in subsequent iterations, the citizen science project can run more efficiently and effectively.

There are various methods to conduct evaluations, such as initial evaluation to gather preliminary information, formative evaluation carried out during implementation, and summative evaluation conducted at the end of the project to identify its effectiveness (Tweddle et al., 2012). The choice of appropriate evaluation methods generally depends on the specific objectives of the project, available resources, and stakeholder needs (Fraisl et al., 2022; US, 2022). However, the most crucial aspect in selecting an evaluation method in this context is considering evaluation as an ongoing effort, enabling improvements at each project stage. Through this approach, evaluations can be conducted proactively by responding to challenges and optimizing strategies to achieve desired outcomes, ensuring that every decision and change made is based on relevant data and feedback. Thus, evaluation serves not only as a tool to assess overall success but also as a mechanism for learning and continuous development to achieve project objectives more effectively (Roche et al., 2020; Tweddle et al., 2012).

CONCLUSION

The article outlines a systematic approach to developing a citizen science project design for ecological learning, specifically in the context of gold mining pollution in the Batanghari River area. The project design process is conducted through a six-stage cycle starting with identifying needs or issues, determining if citizen science is an appropriate approach, designing the project, building communities, managing data, and evaluating the project. This cycle provides a structured approach to citizen science project design in ecological learning.

The adoption of the six-stage cycle in the research was determined through the analysis of several relevant documents. The principal reasons behind the selection were some of the leading citizen science projects in Europe and the US that have achieved results in applying the six-stage cycle. In addition, the six-stage cycle has also demonstrated its success in various research fields, which in turn has further contributed to the development of best practices and new approaches in ecological and environmental sciences, especially in citizen science to SDGs monitoring projects. Overall, the use of the six-stage cycle to design citizen science projects in various research projects has been recognised for its feasibility. Therefore, the design of citizen science projects in this research strives to follow the standards used in major citizen science projects in various countries in the world to achieve feasibility in the design process.

The project design in this research has been specifically tailored to the context of gold mining in the Batanghari River. The assembled project is used to strengthen students' skills in environmental monitoring and to encourage their collaboration with the community in supporting ecosystem conservation efforts in the Batanghari watershed area. To accommodate the objectives to be achieved in accordance with the context of the project problem, the activities of project were structured by adapting a shirk's logic model that refers to the main point, which is the direct link between the potential outcome of citizen science with the activities that were provided (input) and the experience of participants (output). The logic model is a relevant approach to describe how citizen science projects might transform inputs into structured activities that produce specific outputs, eventually influencing outcomes in scientific, social-ecological, and individual level. The employment of logic models is essential in planning and evaluating citizen science projects. They provide a clear framework for linking inputs and activities to desired outputs and broader outcomes, ensuring that citizen science initiatives can deliver significant scientific benefits as well as positive impacts for the communities and individuals involved. Therefore, the use of a logic model to develop the design lends strength to parse out feasible activities to achieve the goals of the citizen science project in this study.

The project design integrates two main elements: a research-based framework and a collaborative project model. Both elements were used to structure and support the implementation of the mini-project in the activity section. The integration of these two elements assigns responsibility to students to collaborate, share knowledge, and apply skills acquired through the inquiry process, interpretation, reflection, and application of scientific knowledge. This enables students to develop ecological concepts in real-world contexts, ultimately enhancing the quality and innovation of the projects developed. The project is also relevant to the raised issue, which is the assessment of the potential or ecological status of the Batanghari River through the measurement of biological quality elements, physico-chemical elements, and hydromorphological quality elements in accordance with European Environment Agency standards. Thus, this citizen science project design not only contributes to ecological learning but also supports river conservation and overall aquatic ecosystem conservation efforts. As a result, this project had an impact on enhancing students' skills in monitoring and collaborating with the community as well as accommodating ecological learning activities intended as an action to assist reduce pollution problems caused by mining activities in the Batanghari River. The specific skills that are expected to improve in the activities through this project are problem-solving skills and environmental awareness derived from environmental literacy for students and enhances sustainability literacy for communities that will face the direct consequences of ecological degradation due to gold mining activities. Advice for the future research is expected to parse relevant theories to determine the design of citizen science projects that are feasible in producing accurate data to strengthen the quality of citizen science projects in the context ecology courses regarding pollution caused by gold mining in Batanghari River issues.

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AUTHOR CONTRIBUTIONS

Susbiyanto Susbiyanto: Develop and design a citizen science project; Study design and Wrote the paper. Topik Hidayat: Conceptualized the research idea; Design a citizen science project; Analyzed and contributed the references used; Reviewed the manuscript. Hertien Koosbandiah Surtikanti: Analyzed and contributed the references used; Reviewed the manuscript. Riandi Riandi: Analyzed and contributed the references used; Reviewed the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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