CHAPTER III
RESEARCH METHODOLOGY

3.1. Research Method and Research Design

3.1.1. Research Method

This study employed a quasi-Experimental design. Two student groups were be observed: the experimental group, which engaged in ESD-STEM learning through the solar cell project, and the control group, which followed the teacher's regular model following inquiry learning. A quasi-experimental approach is chosen because the researcher did not randomly assign participants to the groups.

3.1.2. Research Design

This study adopted a pretest-posttest non-equivalent control group design. In this design, two groups were involved: an experimental group and a control group, both of which underwent pre-tests and post-tests. Each group created products, but they received different treatments. The experimental group worked on the solar cell project through STEM stages by (Widodo, 2021a), while the control group used teacher's regular model following inquiry by Pedaste et al., (2015). The design is illustrated in Table 3.1, as follow.

Table 3.1 Illustration of Research Design

Class	Pre-test	Experiment	Post-test
Experiment	O_1	X (ESD-STEM Learning)	O_2
Control	O_1	- (Teacher's regular model following inquiry)	O_2

Source: (Creswell & Creswell, 2018)

O_1 : Pre-test of students' sustainability action

X : Implementation of the use of the solar cell project

\- : Inquiry learning methods

O_2 : Post-test of students' sustainability action and assessment from the rubric

3.2. Population and Sample

This study takes place at a public junior high school in Bandung, which follows the Merdeka Curriculum. The sample for this research was divided into two classes: Experimental, which consisted of 36 students (8A), and the control class with 33 students (8D). The sampling for this research uses a convenience sampling technique. This technique involves participant selection based on their frequent readiness and availability (Sullivan, 2012).

3.3. Assumptions

a. Solar cell projects in ESD-STEM learning give opportunities to students to innovate a solution in optimizing the use of solar cells to produce electricity.
b. Through working on solar cell projects in ESD-STEM learning, students are involved in engineering design skills and also awareness of the urgency of sustainability action in addressing Climate Action issues.

3.4. Hypothesis

The hypotheses for this study are as follows:

1. **H_0**: There is no significant difference in students' sustainability actions between the experimental group and the control group after learning renewable energy through the solar cell project.
2. **H_1**: There is a significant difference in students' sustainability action between the experiment class and the control class after learning renewable energy through solar cell project.

3.5. Research Instrument

Research data were collected with various instruments as follows:

3.5.1. Engineering Design Skills

Students' engineering design skills in this research were assessed using a Performance-Based Evaluation Rubric (PBER). The rubric was modified by the researcher to suit the learning method applied in this study. PBER is a validated tool commonly used to evaluate engineering design skills in secondary school students throughout the learning process.

The rubric was used by both the observer and the teacher to directly assess students' engineering design skills during the implementation of the ESD-STEM learning activities focused on the solar panel project. In addition to assessing students during the learning process, the rubric was also applied to evaluate students' worksheets and final product outcomes. Each class, both the experimental and control group, consisted of five student groups. In each group, one observer has the role of an external assessor (judgment), while the teacher evaluates all students across the class.

In this lesson, experimental class students made a creative product in groups. The class contains 36 students divided into 5 groups randomly. Making technological products in groups for students has several significant benefits. For example, enhance their engagement and motivation, as well as collaboration skills, while making the technological product. The group work method is most suitable for supporting increased student learning outcomes because to can create a fun learning situation, as well as student learning outcomes can be improved so that the problem can be resolved (Nureki et al., 2024).

The rubric contains several phases as the basis for assessment, each with specific indicators. The phases include problem recognition, problem definition, idea generation, optimal solution selection, solution improvement, presentation and reporting, and design process management. There are 17 indicators for assessing students' engineering design skills in making the technological solutions related to the renewable energy topic and climate change consist of problem identification, analyzing the impact of the problem, identify the solutions/mitigations, analyze the potential challenges, determining size, determining appropriate shape, determining the materials, describe the procedure, estimating the cost, select the solution, create the design, make the prototype, system efficiency, profit, benefit, communication, and completing the technological solution by re-design process. All indicators of the EDS phase are used to assess students' worksheets after STEM-ESD learning through the project. Students' engineering design skills are determined by calculating scores according to a scale obtained based on the worksheet while making the product. This data was evaluated using a 4-point scale, where 1 = poor, 2 = marginal, 3 = satisfactory, and 4 = excellent. To complete the rubric used in this research is presented in Table 3.2 below:

Table 3.2 Performance-Based Evaluation Rubric for Assessing Students' Engineering Design Skills.

Steps	Indicator	Scale			
		Poor **1**	**Marginal** **2**	**Satisfactory** **3**	**Excellent** **4**
Problem Recognition	Students can identify the issue of **burning fossil fuels** and **the use of renewable energy** for the environment	Students **identify the problems that are not clear without observation.**	Students **identify problems based on observation, but unclear.**	Students **identify problems based on observations that are specific.**	Students **identify problems that are specific based on observation and literature study.**
Problem Definition	Students can analyze the impacts of the problems.	Students are only able to **define the only 1 impact of the problem.**	Students are only able to **define 2 impacts of the problem.**	Students are only able to **define 3 impacts of the problem.**	Students are able to define 4 or **more impacts of the problem.**

Steps	Indicator	Scale			
		Poor 1	Marginal 2	Satisfactory 3	Excellent 4
	Students are able to analyze the solutions or mitigations of the problems.	Students are only able to identify the solution, but **not in the form of technology.**	Students are only able to identify **technological solutions,** but it was **not realistic to implement** and **did not answer the problems.**	Students are able to identify **technological solutions** that are **realistic** to implement, but **do not address the problems.**	Students are able to identify **technological solutions** that are **realistic** to implement and **answer the problems.**
	Students are able to analyze potential problems or challenges in a design project.	Students are able to identify challenges in the design project, **but are unable to provide any solutions.**	Students are able to identify challenges and propose solutions, **but the solutions are unrealistic and do not address the issue of non-renewable energy use.**	Students are able to identify the challenges and propose a solution **by considering realistic aspects, or could answer the unrenewable energy used problem**	Students define a solution **by considering realistic aspects and could answer the unrenewable energy used problem**
Idea Generation	**Size:** Determines the size of the prototype that is used in the design.	The size of the prototype is **unrealistic and not proportional to the idea**	The size of the prototype is **realistic but not proportional to the idea**	The size of the prototype is **realistic and proportional but slightly affects the effectiveness of the ideas.**	The size of the prototype is **realistic, proportional, and effectively supports the overall ideas.**
	Shapes: Determine the appropriate shape of the solar cell prototype to ensure efficiency in catching the	The shape of the prototype is **unrealistic, does not support functionality,** and is **not suitable for**	The shape of the prototype is **realistic but not efficient in catching the sunlight and has less**	The shape of the prototype is **realistic, supports in catching the sunlight movements, and is functional, but has less**	The shape of the prototype is **realistic, successful in catching the sunlight movement, stable, and effectively enhances functionality.**

Steps	Indicator	Scale			
		Poor 1	**Marginal 2**	**Satisfactory 3**	**Excellent 4**
	sunlight and functionality.	**catching sunlight.**	**structural stability.**	**structural stability.**	
	Materials: Considering materials that are affordable, environmentally friendly, and easy to find	The materials are **not affordable, not eco-friendly, and not easy to find.**	The materials are affordable, **but not eco-friendly, and not easy to find.**	The materials are affordable, eco-friendly, **but not easy to find.**	**The materials are affordable, eco-friendly, and easy to find.**
	Procedure: Describe the optimal way to capture sunlight based on the tools used to convert solar energy into electrical energy.	The project **does not effectively capture sunlight or store electrical energy in the battery.**	The project captures some sunlight **but does not store the electrical energy in the battery.**	The project functions well in capturing sunlight and storing electrical energy in the battery, **but having minor problems.**	The project **operates optimally, capturing sunlight and storing electrical energy in the battery clearly and effectively.**
	Cost: Students are able to estimate the costs of materials and components needed to build the solar cell project.	The cost is **not listed at all.**	The cost is listed, **but not in detail and not logic.**	The cost is listed, in detail, **but somehow not logic**	The cost is **listed, in detail and logic.**
Optimal Solution Selection	Students are able to select the best solution, ensuring it is not only creative and innovative but also applicable and effective.	Students **did not have a team discussion to select the solution resulting in the selected solution that was plain, simple, and not useful** for	Students did a **team discussion** to select the solution but the **selected solution did not address the problem,** which is for overcoming how **to**	Students selected an optimal solution by **evaluating generated ideas through team discussion,** but the **selected solution was not unique and different** in overcoming **how to optimize the**	Students selected an optimal solution by **evaluating generated ideas through team discussion,** resulting in a **selected solution that was unique, different, and very useful** to overcome **how to optimize the use of solar cells to catch sunlight.**

Steps	Indicator	Scale			
		Poor 1	**Marginal 2**	**Satisfactory 3**	**Excellent 4**
		overcoming **how to optimize the use of solar cells to catch sunlight.**	**optimize the use of solar cells to catch sunlight.**	**use of solar cells to catch sunlight.**	
Solution Improvement	Students are able to create the designs of the prototypes of the best solutions options they've chosen.	Students drew the design **but it was not providing any details of materials and limitations on the design drawing.**	Students drew the design **but did not provide enough detail in the materials and limitations**	Students drew the design and provided **only the details in materials or limitation of the design.**	Students drew **a complete design and provided the details including the technology used.**
	Students are able to make the prototype based on the design they've made.	The prototype **was not made.**	The prototype is made **but not finished.**	The prototype is simple **but not solve the problem mentioned.**	The prototype is **innovative and relevant to the problem mentioned.**
	Efficiency: Propose a system that is efficient in terms of the solar cell success to generate the light to electricity shown by functional products to catch the sunlight with proper	The **system does not work.**	The system functions **but has noticeable inefficiencies (based on the descriotiption).**	The system is reasonably efficient, effectively capturing sunlight; **however, the design or infrastructure has limitations that reduce overall performance or energy optimization.**	The system is **highly efficient, maximizing energy capture and storage, and well-optimized design/infrastructure support.**

Steps	Indicator	Scale			
		Poor 1	Marginal 2	Satisfactory 3	Excellent 4
	design/infrastructure.				
	Profit: Students are able to analyze the profit by proving that using the prototype is significantly more beneficial than not using it.	Students are **unable to analyze or provide justification regarding the benefits of using the prototype**	Students attempt to analyze the benefits of using the prototype **but provide limited or unclear justification**	Students are **able to analyze the benefits of using the prototype or provide a generally clear justification of its advantages over not using it.**	Students **clearly and convincingly analyze the benefits of using the prototype, providing well-reasoned justification that demonstrates its advantages in practical application.**
	Benefits: Students are able to analyze and explain the benefits in environmental, social, and economic aspects of using their solar cell product machine compared to not using it.	The idea **pollutes the environment and does not provide benefits to society and the economic aspect.**	The idea **has a small positive impact on the environment but provides little benefit to society and the economic aspect.**	The idea **has a decent positive impact on the environment and provides a fair benefit to society and the economic aspect**.	The idea has a **highly positive impact on the environment and is very beneficial to society and the economic aspect.**
Presentation and Reporting	Students are able to communicate the technological solutions by mentioning the main problem chosen, the	Students are **unable to communicate the technological solution and do not mention the main**	Students communicate the technological solution, **but not mention the main problem,**	Students mention the main problem, explain how the prototype works, **but not describe its environmental, social and**	Students **clearly state the problem, explain how the prototype works as a solution, and describe its environmental, social, and economic benefits.**

Steps	Indicator	Scale			
		Poor 1	**Marginal 2**	**Satisfactory 3**	**Excellent 4**
	technological solution, how it works, and benefits.	**problem or how it works or its benefits.**	**how it works, or the benefits.**	**economic benefits.**	
Design Process Management	Students are able to complete the prototype with the final design in allotted time by controlling the design process through activities that involve working in teams	Students did **not make changes or any improvements** in completing the final result of their prototype.	**Students refine their prototype without considering anything.**	Students **refine their prototype but only consider one** of the results of the trial or feedback they got.	Students **refine their prototype based on the trial test results as well as feedback** relevant to the subject matter.

Source: (Jin, 2015, Crismond & Adams, 2012)

3.5.1.1 Engineering Design Skills Instrument Analysis

Before being distributed, the instrument was validated by experts' judgment, can be seen in Appendix 5. Then the instrument was revised and used by the researcher, observer, and teacher during the learning activity. The collected data was calculated to get the average using Excel and converted to a 100-scale. After calculating the score of students' engineering design skills, the data was analyzed.

3.5.2. Sustainability Action Questionnaire

Student Sustainable action was measured using the Environmental Citizenship Questionnaire (ECQ). This instrument is used as a basis for developing an instrument for understanding sustainability. The Environmental Citizenship Questionnaire (ECQ) is provided as a validated measurement for assessing secondary school students' responsible pro-environmental behavior and social

This instrument is tested before (Pretest) and after (Posttest) the learning activities in both in control and experimental class. The descriptive analysis of student action is presented in Table 4.10 with a range of scores 1-4. To analyze students' pretest and posttest results, statistical calculation is used through difference tests to see the influence of ESD-STEM learning. The score of the pretest result is used to identify students' initial actions before carried out the learning activity, while the scores of the posttest result are used to measure the action taken by students after the learning process.

The explanation begins with the meaning of data that has been processed statistically. It is continued by the result of STEM learning activity while making the product. Last, deeper analysis occurred in students' sustainability action using SPSS. An explanation of each sustainability action indicator is detailed in this subchapter. Quantitative and qualitative data that included in research results were analyzed systematically. The normality test and homogeneity tests are carried out first as a prerequisite. The questionnaire consists of 52 items: the past, present, and future action indicator is covered by 28 items and the competencies are covered by 24 items.

Respondents were asked to indicate how much they agreed with both the positive and negative statements on a 4-point Likert scale. Table 3.3 shows the blueprint of sustainability action instruments before validation, detailed statements shown in Appendix 2.

Table 3.3 Blueprint of Sustainable Action Questionnaire (Before Validation)

No	Indicator	Number of questions				Total Number
		Renewable energy	Climate change's impact	Adaptation to climate change	Prevention and mitigation	
1	Past, present, and future actions	1,2,3,4,5,6	7,8,9,10,11,12,13,14	15,16,17,18,19,20,21,22,23	24,25,26,27,28,29,30	30
2	competences	1,2,3,4,5,6	7,8,9,10,11,12	13,14,15,16,17,18	19,20,21,22,23,24	24

3.5.1.2 Sustainability Action Instrument Analysis

Before being distributed, the instrument was validated by experts' judgment. The result is attached in Appendix 3. Then the instrument was revised and tested by the student. After measuring the scores of the pre-test and post-test, the data were analyzed using IBM SPSS to see the validity and reliability.

a) Validity

Validity points to a given result's accuracy, usefulness, and significance. The interpretation of the validity score is shown in Table 3.4.

Table 3.4 Validity Interpretation

rValue	Interpretation
r≥0.204	Valid
r≤0.204	Not Valid

The result of the validation analysis of the sustainable action questionnaire on past, present, and future indicators is presented in Table 3.5 below:

Table 3.5 Recapitulation of Validity of Sustainable Action Questionnaire Past, Present, and Future Indicators

Item number	First trial Validity			Valid	Second trial Validity			Valid	Conclusion
	Past action	Present action	Future action		Past action	Present action	Future action		
1	0.332	0.512	0.274	Valid					Accepted
2	0.421	0.491	0.526	Valid					Accepted
3	0.092	0.090	0.337	Not valid	0.483	0.411	0.358	Valid	Accepted
4	0.445	0.427	0.005	Not valid	0.383	0.243	0.453	Valid	Accepted
5	0.056	0.051	0.460	Not valid	0.736	0.512	0.383	Valid	Accepted
6	0.398	0.443	0.463	Valid					Accepted
7	-0.199	-0.321	-0.185	Not valid	0.653	0.469	0.376	Valid	Accepted
8	0.518	0.517	0.430	Valid					Accepted
9	0.101	0.239	0.244	Not valid	0.666	0.712	0.533	Valid	Accepted
10	0.056	0.033	0.310	Not valid				Valid	Rejected
11	0.469	0.634	0.451	Valid					Accepted
12	0.234	0.430	0.516	Valid					Accepted
13	0.478	0.440	0.439	Valid					Accepted
14	0.249	0.430	0.337	Valid					Accepted

Item number	First trial Validity			Valid	Second trial Validity			Valid	Conclusion
	Past action	Present action	Future action		Past action	Present action	Future action		
15	0.023	0.011	0.042	Not valid	0.605	0.599	0.622	Valid	**Accepted**
16	0.428	0.631	0.557	Valid					**Accepted**
17	-0.059	-0.075	0.062	Not valid					**Rejected**
18	0.411	0.439	0.587	Valid					**Accepted**
19	0.380	0.376	0.163	Valid	0.684				**Accepted**
20	0.549	0.574	0.528	Valid					**Accepted**
21	0.574	0.678	0.512	Valid					**Accepted**
22	0.302	0.084	0.462	Not valid	0.689	0.684	0.301	Valid	**Accepted**
23	0.583	0.663	0.496	Valid					**Accepted**
24	0.525	0.648	0.503	Valid					**Accepted**
25	0.334	0.155	0.454	Not valid	o	0.241	0.354	Valid	**Accepted**
26	0.422	0.607	0.502	Valid					**Accepted**
27	0.525	0.621	0.589	Valid					**Accepted**
28	0.033	0.602	0.468	Not valid	0.710	0.441	0.684	Valid	**Accepted**
29	-0.124	-0.136	-0.072	Not valid	1	1	1	Valid	**Accepted**
30	0.270	0.242	0.500	Valid					**Accepted**

After the first and second trials, it was found that 2 out of 30 questions were invalid, but since the valid statements already represented all sub-indicators, the number of statements used for the instrument to measure students' sustainability of climate action in the past, present, and future indicators was 28 numbers. The same test occurred in students' competences. The result of the validation analysis of the sustainable action questionnaire on the competencies indicator is presented in Table 3.6, below:

Table 3.6 Recapitulation of Validity of Sustainable Action Questionnaire Past, Present, and Future Indicators

No	Validity First trial		Explanation	Validity second trial		Conclusion
1	-0.135		Not valid and revised	0.726		**Accepted**
2	0.419		**Valid**			**Accepted**
3	0.284		**Valid**			**Accepted**
4	0.611		**Valid**			**Accepted**
5	0.486		**Valid**			**Accepted**
6	0.397		**Valid**			**Accepted**

No	Validity First trial		Explanation	Validity second trial		Conclusion
7	0.392		**Valid**			**Accepted**
8	0.388		**Valid**			**Accepted**
9	0.121		Not valid and revised	0.734		**Accepted**
10	0.455		**Valid**			**Accepted**
11	0.313		**Valid**			**Accepted**
12	0.441		**Valid**			**Accepted**
13	0.448		**Valid**			**Accepted**
14	0.567		**Valid**			**Accepted**
15	0.291		**Valid**			**Accepted**
16	0.287		**Valid**			**Accepted**
17	0.423		**Valid**			**Accepted**
18	0.444		**Valid**			**Accepted**
19	0.068		Not valid and revised	0.745		**Accepted**
20	0.317		**Valid**			**Accepted**
21	0.568		**Valid**			**Accepted**
22	0.506		**Valid**			**Accepted**
23	0.376		**Valid**			**Accepted**
24	0.469		**Valid**			**Accepted**

After checking the validity, reliability checked to know the coherent for set items questions. The reliability result presented below:

Table 3.7 Reliability Result of Questionnaire

No	Items	Reliability	
		First Trial	Second Trial
1	Past, Present, Future items	0.956	0,958
2	Competences	0.723	0,955

The process of developing an instrument starts with understanding each indicator that has been developed (Hadjichambis & Paraskeva-Hadjichambi, 2020). The researcher then modifies the instrument items by the topic of sustainable development that has been raised, which is renewable energy, which is linked to the topic of science learning. For this reason, the researcher has prepared 55 items that will be tested. Before that, the instrument went through the stages of expert judgment and revision to see the diction, suitability of indicators, and the provision of concepts at the junior high school level. Then the researchers tested the instrument on 94 students, and the results showed that 52 out of 55 items were declared valid after being processed using SPSS software. The instrument trial aims to test the validity and degree of reliability of the instrument, to ascertain whether the statements can be accepted and understood by the respondents, and to determine the length of time needed to fill out the instrument. All valid items will be used in measuring students' climate action.

In the competency indicator, all aspect meets the criteria. So, the number of climate action on renewable energy topic instruments used in the study after conducting the validity test was 52 statements items with a choice of various options according to the indicator which are, never, rarely, often, always for past and present indicators, won't do, maybe will do, trying to do, sure will do for future indicators and really incapable, unable, able and very capable for competences indicators. The complete instrument items can be seen in the appendix. The blueprint of the sustainable action questionnaire, after validation, is given in Table 3.8. The detail questions shown in Appendix 4.

Table 3.8 Blueprint of Sustainability Action Questionnaire (After Validation)

No	Indicator	Number of questions				Total Number
		Renewable energy	Climate changes' impact	Adaptation to climate change	Prevention and mitigation	
1	Past, present, and future actions	1,2,3,4,5,6	7,8,9,10,11,12,13	14,15,16,17,18,19,20,21	22,23,24,25,26,27,28	28
2	competences	1,2,3,4,5,6	7,8,9,10,11,12	13,14,15,16,17,18	19,20,21,22,23,24	24

The instrument uses simple language and is easily understood by junior high school students. Examples of instruments that have passed the validity test and reliability test can be seen in Table 3.9 on the next page.

Table 3.9 Example of Sustainability Action Items

Indicator	Statement
Past, present, and future action	*Saya menggunakan kipas angin ketika diperlukan saja agar tidak boros listrik*
Competences	*Saya menanam dan merawat tanaman di sekitar rumah untuk meningkatkan penyerapan karbon dioksida.*

3.6 Research Procedures

The procedure in this study was divided into three stages consist of research preparation, research implementation (data collection), and completion (data processing, analysis, and conclusion drawing). The details of the activity are described as follows.

3.6.1. Preparation Stage

There are various key procedures to take during the preparatory stage. Researchers begin by establishing the research problem. Following that, researchers investigated national, global and ideal issues to see a problem and insights on ESD-STEM learning, engineering design skills, and students' sustainability action. After that, the research proposal was developed, which outlined the study problem, research questions, and operational definition to direct the research procedure. Furthermore, research materials were created and employed in instructional activities. Additionally, instructional resources, including media, lesson plans, and student worksheets, and observation sheet were prepared. The development of research instruments was done through the engineering design skills and the sustainability action of students. Before being subjected to the validity and reliability testing, the instrument was evaluated by several expert through expert judgement and passed several revision steps. Moreover, administrative preparations were completed, including discussing with the school's science teacher about the study methods and requesting official research permits from the school Appendix 1. The second stage involves creating a study instrument, including rubrics and a questionnaire, to assess two variables. The lecturer will analyze the instrument before distributing it to students. Furthermore, prepare instructional resources, including media, lesson plans, and student worksheets. The researcher selects a population that fulfills the study's parameters.

3.6.2. Implementation Stages

The implementation stage consisted of several activities, as follows:

1. Giving a pretest to students

   The pretest of sustainability actions was administered outside of the meeting, both control and experimental classes, before the learning activity. Students were given a pretest to assess their knowledge and abilities in sustainability. ESD-STEM learning was used in the experimental class, while the teacher's regular learning, following inquiry-based stages, was done in the control class.

2. Giving treatment in a class

   After the pretest was conducted, students began learning about renewable energy and its effects on climate change. The experimental group received treatment through ESD-STEM learning activities centered on a solar cell project, while the control group continued learning through the teacher's regular learning which in this study following inquiry learning stages adjusting the students in control class.

   During the learning activities, observations were conducted by both an independent judge and the teacher to assess students' engineering design skills using a designated rubric. In addition, observations of the learning process were also carried out to identify the stages of learning progression. Moreover, the differences in the implementation between the experimental class and the control class are presented in Table 3.10 on the next page, the detail can be seen in Appendix 6:

Table 3.10 Learning Activity in Experimental Class and Control Class

Meeting	Experiment Class	Learning Stages		Control Class
		STEM model	**Teacher's regular model**	
At Home	Students carried out an observation of their environment related to energy problem especially in fossil energy used and renewable energy.	**Problem Identification**	**-**	No task
1	Pray before learning begins Students' attendance checking Questions and answer sessions with students about climate change due to the fossil fuels caused and renewable energy.	**Introduction**	**Orientation**	Pray before learning begins Students' attendance checking Questions and answer sessions with students about climate change due to the fossil fuels caused and renewable energy. Students watch a video related to energy issues and take notes on key information from the video. Students conduct research on energy issues in West Java and similar issues in their local environment, recording important findings.
			Conceptualization	Students formulate questions based on the video they have watched independently as well as from their group discussions.

Meeting	Experiment Class	Learning Stages		Control Class
		STEM model	**Teacher's regular model**	
				Students engage in a discussion about the issue of dependence on fossil fuels. Students watch a video about solar energy installations and record the advantages and disadvantages. Students discuss and summarize the main ideas to answer the initial guiding questions. Students propose simple technological solutions or products to help address the energy crisis.
	Teacher showing a video about energy shortage problem from YouTube. Students divide into 5 groups. Students carry out a group discussion to investigate and explore problems national (YouTube video), Province (Independent research), and Environment (Independent observation that already task before) by fulfilling the worksheet.	**Problem Identification**		
	Students carry out a group discussion about several technology solution using solar cell including title, materials and tools, cost, benefit (social, environmental, benefit), and procedures.	**Think**		
	Students design a technological solution they have chosen by arranging the required tools and materials, estimating the cost, outlining the procedures, and drawing the product they will create.	**Design**		
2	Students create the solar cell project in group based on their design guided by the teacher. Students continue their work out of meetings. (This process is watched by the teacher and observer)	**Create**	**Investigation**	Students carry out the construction of the technological solution they proposed.

Meeting	Experiment Class	Learning Stages		Control Class
		STEM model	**Teacher's regular model**	
3	Student continue create the product in group. Students continue their work out of meetings. (This process is watched by the teacher and observer)	**Create**	**Investigation**	Students carry out the construction of the technological solution they proposed.
4	Students presented their product. Students conducted testing of their product using flashlight as light source. Student got an evaluation from peer and teacher.	**Testing**	**Conclusion**	Students compare the results of their testing with the hypotheses they previously formulated. Students conduct an evaluation of the technological solution they have created.
			Discussion	Students present the technological solution they have developed. Students receive feedback in groups from other student groups. Students receive feedback on their technological product from the teacher.
Out of meeting	• Students redesign the product based on the feedback given before out of the meeting. (This process is watched by the teacher and observer)	**Refinement of Technology**	**-**	-
At Home	Students present the improvement final project. Students are given the post-test about sustainability action. Students make a publication of their project in reducing the		**-**	-

Meeting	Experiment Class	Learning Stages		Control Class
		STEM model	Teacher's regular model	
	climate change by uploading an explanation and presentation of their project in social media (Instagram, Facebook, or YouTube)			

3. Giving a posttest to students

   At the end of the learning activity that occurred in the last meeting for the experimental and control classes, posttests are given out of meeting under teacher and observer monitoring. The students were given the sustainability action questionnaire using google forms.

4. Interview

   The interviews were conducted with students to gather feedback on the ESD-STEM learning.

3.6.3. Completion Stage

After collecting the data, the researcher analyzed the data quantitatively and qualitatively. For students' engineering design skills, from rubric, interview, and observation sheets, for students' sustainability action, from a questionnaire and interview. The quantitative data were analyzed using SPSS and Excel. Then interpret the result to become a discussion and conclusion also completing the research paper. The researcher also documenting the process which can be seen in Appendix 16. Furthermore, for academic integrity, several checking occurred including, similarity check (seen in appendix 18), AI checker (seen in Appendix 19), and submission to Sinta 2 article (seen in Appendix 17).

3.6.4. Research Flow

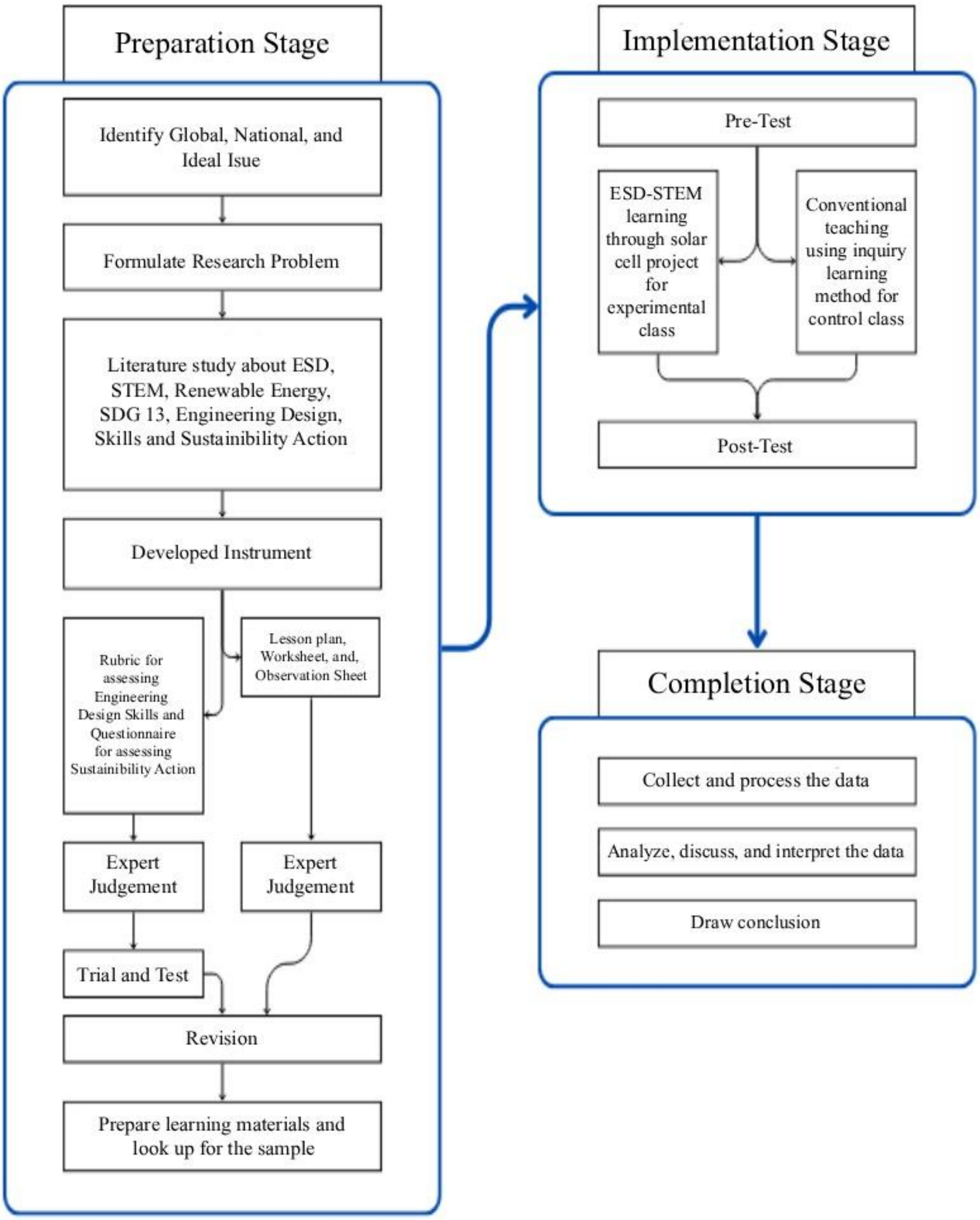

Figure 3.1: Research Flow

3.7. Data Analysis of Results

After gathering data on students' engineering design skills and sustainability actions, the analysis conducted in quantitative and qualitative analysis for each variable. The stages are as follows:

3.7.1. Engineering Design Skills

Quantitative data for students' engineering design skills (EDS) were assessed using PBER rubric that already modified by the researcher. Each phase scored on a scale from 1 to 4, with 4 being the highest and 1 being the lowest score. The students' scores were first be summed and then averaged to determine the mean score of their engineering design skills.

The assessment of students’ engineering design skills in the experimental class obtained previously was converted to a scale of 100 based on Purwanto’s (2008) criteria to determine the students’ ability. The following is the assessment category table according to Purwanto (2008) presented below:

Table 3.11 Category of Engineering Design Skill

Category of Engineering Design Skill	Value
Very Good	86-100
Good	76-85
Fair	60-75
Poor	55-59
Very Poor	<55

Source: (Purwanto, 2008)

In addition, a qualitative analysis was conducted to describe students’ engineering design skills during the learning activities. This analysis was carried out through direct observation. Five observers were assigned to observe five student group, with each group being observed by one observer. During the observation, each observer was provided with an observation sheet prepared by the researcher to guide and support the observation process during the learning activities, seen in Appendix 7. The observation sheet contained detailed descriptions of students’ learning process following ESD-STEM learning method to observe how students applied their design skills in real-time.

3.7.2. Sustainability Action

Quantitative analysis used to determine students' sustainability action. The data were collected from questionnaire that given to the students at the beginning and at the end of the learning activity. The pretest and posttest were in a form of daily statements related to students' action in daily life and converted into numbers to facilitate analysis and interpretation. The questionnaire consists 2 types of statements which are positive and negative statements. For positive statements, the score ranges from 1 (lowest) to 4 (highest), and for negative statements, the scoring is reversed. To facilitate the analysis and interpretation, researcher used several tests.

Prerequisite tests, including normality and homogeneity tests, are necessary to determine the appropriate data analysis method for measuring student's sustainability action. Normality test is the test checks whether the data follows a normal distribution. In this study, the Shapiro wilk test will analyze the pre-test and post-test results. If the significance value is <0.05, the data is not normally distributed meanwhile, if the significance value is >0.05, the data is normally distributed. After conducting the normality test, if the data is normally distributed, homogeneity test can be conduct. The homogeneity test determines whether the control and experimental groups come from the same population. If the data is normal, the homogeneity test will occur. The Levene test will be used for this study since the data is in scale form. If the significance value is <0.05, the data is not homogeneous meanwhile, if the significance value is >0.05, the data is homogeneous. Furthermore, the hypothesis test determines the relationship between the treatments and the research outcomes. If the data is normally distributed, a paired test will be used for hypothesis testing. If the data is not normally distributed, the Mann-Whitney U test will be applied. The gain score calculation will be applied if the hypothesis in both classes' pre-test results is significantly different. In this research, the data is not normally distributed, so the researcher used the Mann-Whitney U-test to determine the significant difference between the experimental group and the control group. The pre-test result between both classes is significantly different, so the researcher uses the gain score for the pre-test and post-test between each class to know the increase between both classes. After that, the N-Gain test will measure the improvement in students' sustainability actions before and after completing the solar cell project in the ESD-STEM learning. Prior to calculating the N-Gain, normality, and hypothesis testing will be conducted on the pre-test and post-test data for sustainability actions.