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# Development of a Guided Inquiry-Based Experimental Design for the Synthesis of GO-PANI from Coconut Shell Charcoal

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**ABSTRACT**
This study aims to develop an experimental design based on guided inquiry for the synthesis of GO–PANI composites derived from coconut shell charcoal, packaged in a student worksheet. The development follows the Research and Development (R&D) model, consisting of three main stages: preliminary study, research, and instructional material development. Preliminary studies analyze the needs through syllabus and journals. The study was in the form of a preliminary test in the laboratory in the synthesis of graphic oxide (GO) with a modified Hummers method, then composed with polyanilin through in situ polymerization. Development of teaching devices in the form of experimental and student worksheet designs. The student worksheet was structured according to guided inquiry phases: orientation to the problem, problem formulation, planning and conducting experiments, data analysis, and drawing conclusions. Validation by three experts indicated that the experimental design and student worksheet were rated highly valid, with an average r value of 0.94. A feasibility test involving ten students showed very positive responses, with an average feasibility score of 92.2%. The success of the experimental design is reflected in its ability to integrate locally sourced biomass-based material synthesis with a contextual and applicable guided inquiry approach. In addition, characterization of the synthesized products using FTIR and SEM confirmed the successful formation of the GO–PANI composite. This research contributes to the development of instructional tools relevant to modern chemistry education while supporting the principles of renewable energy and the sustainable utilization of local resources.

**Keywords:** Coconut shell charcoal, Experimental design, GO-PANI, Guided inquiry, Student worksheet.

## Introduction

In recent decades, there has been a growing call to improve the quality of Science, Technology, Engineering, and Mathematics (STEM) education at the undergraduate level (Laursen, 2019). The ability to design experiments is considered a core competency for graduates of STEM programs, as it enhances scientific performance skills. However, many undergraduate STEM students still lack adequate experimental skills, largely due to limited opportunities in laboratory courses to effectively practice and develop those skills (Restuccia & Taska, 2018).

Laboratory experiments are an effective method for providing meaningful learning experiences, as they foster both conceptual understanding and measurable scientific skills (Amalia et al., 2020). Experimental activities begin with designing an experimental setup aimed at obtaining optimal results and aligning laboratory procedures with established standards (Sitorus & Samosir, 2022; Sunarya et al., 2022). Experimental design plays a critical role as a systematic approach to developing effective experiments, enabling the testing of input variable changes and identifying their effects on the output (Ahmad et al., 2019; Siska & Salam, 2012; Sitorus & Samosir, 2022).

In line with the nature of experimentation, chemistry education at the university level is expected to be conducted through inquiry-based approaches in order to enhance students' thinking skills, scientific attitudes, work habits, and communication abilities—key aspects of life skills (Depdiknas, 2007). The guided inquiry model in chemistry instruction can support students in analyzing concepts, instructions, and experimental procedures, thereby fostering critical thinking processes (Firdaus & Wilujeng, 2018). Through guided inquiry, instructors provide students with extensive guidance or prompts throughout the learning process (Lovisia, 2018).

Research has shown that the guided inquiry model is effective in improving both student learning outcomes and engagement, with respective increases of 16% and 19.36%. The average cognitive learning outcome in the experimental group (83.17) was higher than that in the control group (77.33), with an N-gain categorized as moderate (Annisa et al., 2020). Similar studies have also demonstrated that guided inquiry-based worksheets effectively enhance scientific performance, as they reflect the scientific method and are thus well-suited for use in chemistry laboratory activities (Widyaningrum & Wijayanti, 2019).

This study aims to develop an experimental design for the synthesis of graphene oxide-polyaniline (GO-PANI) integrated with a guided inquiry-based learning model. It addresses pressing global issues such as increasing energy consumption, population growth, the depletion of fossil fuels, and global warming—factors that emphasize the urgent need to transition toward alternative energy sources. A key challenge lies in developing materials that are not only highly efficient and low-cost but also sustainable in the long term. A study emphasizes the importance of education that fosters observation and the application of sustainable energy to raise awareness and interest among students (Chien et al., 2018). This has driven the development of alternative energy technologies, including solar energy, which is particularly suitable for implementation in Indonesia—for example, Dye-Sensitized Solar Cells (DSSCs) (Afandi et al., 2016; Yulnesty et al., 2024).

The use of coconut shell charcoal as a sustainable local material presents a promising innovation in DSSCs development. Coconut shells are often perceived as waste with no economic value, and therefore are frequently discarded without further processing. This practice can lead to waste accumulation, which may eventually cause environmental pollution (Rizwan et al., 2024). However, coconut shells are actually rich in organic compounds that can be processed into carbon sources. Coconut shells are rich in organic compounds that can be processed into carbon sources. Carbon itself has many allotropes, such as graphene and graphite, which hold great potential for energy applications (Inagaki & Kang, 2014). Utilizing this waste not only supports the concept of a circular economy but also aligns with the Sustainable Development Goals (SDGs), particularly Goal 12 on responsible consumption and production and Goal 7 on affordable and clean energy (Nations, 2015). Converting organic waste into high-value materials for renewable energy applications represents a tangible contribution to reducing environmental impact and enhancing global sustainability.

On the other hand, one of the key components of DSSCs is the counter electrode. The GO-PANI composite has shown potential as a material for DSSC counter electrodes (Sunarya et al., 2020; Wei et al., 2021). Graphene oxide (GO), a graphene derivative containing hydrophilic functional groups such as hydroxyl, carboxyl, and epoxy, has strong potential as an active material for supercapacitors (Fauziah et al., 2023). GO is highly suitable for compositing with polyaniline (PANI), which is a promising candidate for counter electrode materials due to its high conductivity, good stability, and favorable porosity (El-Sharkaway et al., 2019; Sunarya et al., 2023). However, PANI has certain drawbacks, such as low solubility and poor mechanical properties caused by the aggregation of its long polymer chains (Reza et al., 2022; Tiwari, 2007). To overcome these limitations, PANI is often polymerized with nanomaterials such as graphene to enhance its performance.

This study reports the development of an experimental design and student worksheet for the synthesis of GO-PANI utilizing coconut shell charcoal waste as a carbon source. To date, no studies have reported the development of an experimental design and guided inquiry-based worksheet for synthesizing GO-PANI from natural carbon sources like coconut shell charcoal, despite its potential to produce environmentally friendly and low-cost materials for electronic devices such as DSSCs. The success of GO and GO-PANI synthesis in this study is confirmed through FTIR and SEM characterizations (Putri & Supardi, 2023; Razak et al., 2024).

Thus, the development of an experimental design that adopts a guided inquiry-based learning approach on the topic of energy conservation serves as an effective strategy to enhance students' scientific performance and raise their awareness of sustainable energy issues. The novelty of this study lies in the integration of a contextual learning approach with the synthesis of functional GO-PANI materials derived from biomass waste, specifically coconut shell charcoal. Through this approach, chemistry learning becomes not only theoretical but also practical and aligned with global challenges in the energy sector.

## Method

This study employed the Research and Development (R&D) method, which involves the process of developing or refining educational products. The product developed in this study is an experimental design for the synthesis of GO-PANI from coconut shell charcoal. The R&D process consists of three main stages: preliminary study, research, and development (Okpatrioka, 2023).

The initial stage involved a needs analysis through a review of syllabi and scientific journals to identify the need for innovation in teaching renewable energy topics. During this stage, a concept map and concept analysis were also prepared. Concept maps and concept analysis organize main ideas and clarify relationships between relevant concepts. They provide a foundation for creating structured learning materials aligned with objectives and help identify key concepts for students to master. In the research phase, an experimental design was created for the synthesis of GO using the modified Hummers method and for GO-PANI synthesis via in situ polymerization, followed by characterization using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). The experimental design included independent variables (material composition), dependent variables (characterization results), and controlled variables (temperature and raw materials).

The development phase included the preparation of a student worksheet based on the experimental design, along with assessment grids and scoring rubrics. The student worksheet was validated by three lecturers specializing in Chemistry Education. Two of them, as content experts, evaluated the clarity and relevance of the material, while the third, an expert in educational design, assessed aspects such as construction, language, and alignment with the guided inquiry approach. Additionally, the worksheet's feasibility was evaluated by ten Chemistry Education students at UIN Sunan Gunung Djati Bandung who were enrolled in the Energy Conservation course.

Qualitative data consisted of a description of the student worksheet's appearance, while quantitative data included validation and feasibility scores. The validation test employed a questionnaire using a 3–1 rating Likert scale (3 = Good, 2 = Fair, 1 = Poor), covering aspects such as content, format, language, and illustrations. The validity value (r value) was obtained from the total score of all respondents divided by the number of items and respondents, and then compared to the critical r value of 0.30. If r value ≥ 0,30, the instrument is considered valid (Sugiyono, 2017). The interpretation of the r value is presented in **Table 1**, with the formula used for the validity test also provided.

Table 1. Interpretation of worksheet validity

| No. | r Value | Interpretation |
|---|---|---|
| 1. | 0,80 ≥ R ≤ 1,00 | Very High |
| 2. | 0,60 ≥ R ≤ 0,80 | Fairly High |
| 3. | 0,40 ≥ R ≤ 0,60 | Slightly Low |
| 4. | 0,20 ≥ R ≤ 0,40 | Low |
| 5. | 0,20≥ R ≤ 0,00 | Very Low |

Source : Sugiyono (2017)

Feasibility testing was conducted through a questionnaire to evaluate the effectiveness of the worksheet in supporting the understanding and implementation of the material. The questionnaire included indicators evaluating content, presentation, language, and practicality. A 3-1 rating Likert scale (3 = Good, 2 = Fair, 1 = Poor) was used to assess responses. The questionnaire results were accumulated in the form of a feasibility percentage, with the score criteria presented in **Table 2** and calculated using the following formula.

$$\text{Feasibility Percentage (\%)} = \frac{\text{score obtained}}{\text{maximum score}}\, x\ 100\%$$

Table 2. Feasibility value criteria

| No. | Interval (%) | Interpretation |
|---|---|---|
| 1. | 90% - 100% | Very Feasible |
| 2. | 80% - 89% | Feasible |
| 3. | 70% - 79% | Fairly Feasible |
| 4. | 60% - 69% | Less Feasible |
| 5. | <60% | Not Feasible |

Source : Farida (2019)

## Results and Discussion

The results of this research on the development of a guided inquiry-based experimental design for the synthesis of GO-PANI from coconut shell charcoal include: (1) the results of the needs analysis conducted during the preliminary study phase, (2) the experimental design outlining the procedural steps for synthesizing the GO-PANI composite, and (3) the development outcomes of the student worksheet for the synthesis of GO-PANI from coconut shell charcoal, which underwent both validity and feasibility testing.

The preliminary study was carried out through an analysis of the syllabus for the Energy Conservation course and a review of several relevant scientific articles. The results of this analysis indicate that learning activities related to renewable energy—particularly the practice of synthesizing alternative materials for solar cells such as DSSCs—are still rarely implemented in the form of inquiry-based experiments. Students generally only understand the concept of renewable energy theoretically, without direct experience in designing or conducting applicable experiments.

In addition, the needs identification was also carried out through a literature review and concept mapping. It was found that the guided inquiry approach has high potential to be implemented, as it can guide students toward scientific performance, such as formulating problems, developing hypotheses, conducting observations, and drawing conclusions. These findings served as the foundation for developing a student worksheet that integrates the synthesis of GO-PANI materials as a form of contextualized learning.

The experimental design began with a preliminary test on the synthesis of graphene oxide (GO) using a modified Hummers' method, with coconut shell charcoal as the carbon source. This method was selected due to its faster and safer procedure compared to other techniques—for instance, replacing $KClO_3$ with $KMnO_4$ to avoid the formation of explosive $ClO_2$ gas, and substituting $HNO_3$ with $NaNO_3$ to reduce the generation of acid mist (Alam et al., 2017; Hummers & Offeman, 1958). In this study, further modifications were made by replacing $NaNO_3$ with $H_3PO_4$ to minimize the evolution of toxic gases ($NO_2$ and $N_2O_4$), reduce ionic waste, and enhance safety and reaction control at the laboratory scale (Alam et al., 2017).

The procedure began with the graphitization of coconut shell charcoal, followed by oxidation using a mixture of strong acids ($H_2SO_4$ and $H_3PO_4$) and a strong oxidizing agent ($KMnO_4$) to produce graphene oxide (GO) containing functional groups such as hydroxyl, epoxy, and carboxyl. The oxidation reaction was then terminated by the addition of $H_2O_2$ into the mixture. The synthesis scheme is presented in **Figure 1**.

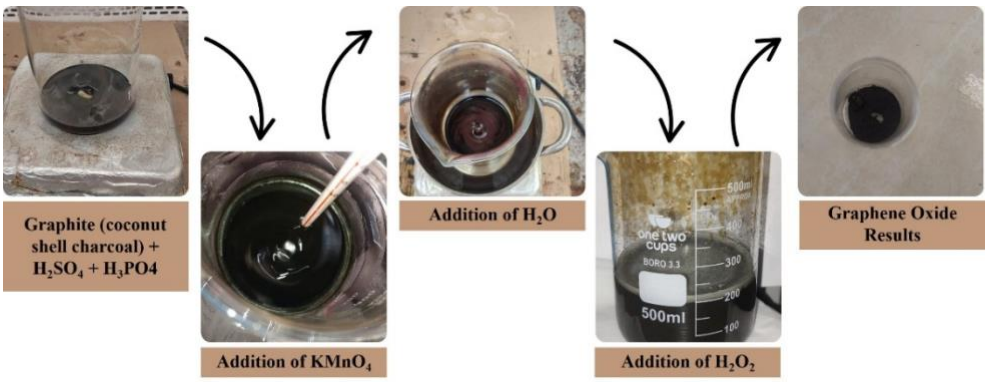


Figure 1. Synthesis of graphene oxide from coconut shell charcoal

GO was then composited with polyaniline (PANI) through an in situ polymerization method at a low temperature range (5–8 °C) under acidic conditions. Typically, high-quality GO/PANI composites are synthesized at 0 °C using an ethylene glycol bath; however, such low temperatures are difficult to achieve and control using only an ice bath. Therefore, in this study, the reaction temperature was modified to a more practical range of 5–8 °C, which remains effective for the polymerization of aniline, although not as low as 0 °C. An illustration of the in situ polymerization process is shown in **Figure 2**.

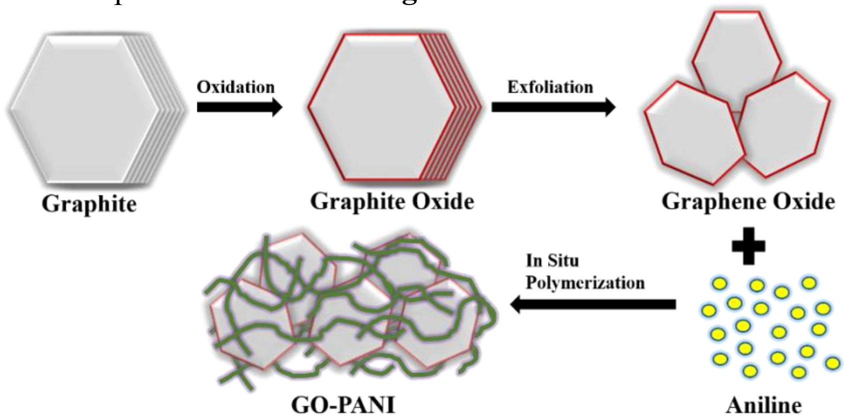


Figure 2. Illustration of the in situ polymerization process of go-pani via in situ polymerization

At this stage, aniline as the monomer was dissolved in HCl and $H_3PO_4$, followed by the addition of an oxidizing agent (APS) along with GO to form the GO–PANI composite. The synthesized GO–PANI was then characterized using FTIR and SEM to identify functional groups and surface morphology. The synthesis scheme of GO–PANI is illustrated in **Figure 3**.

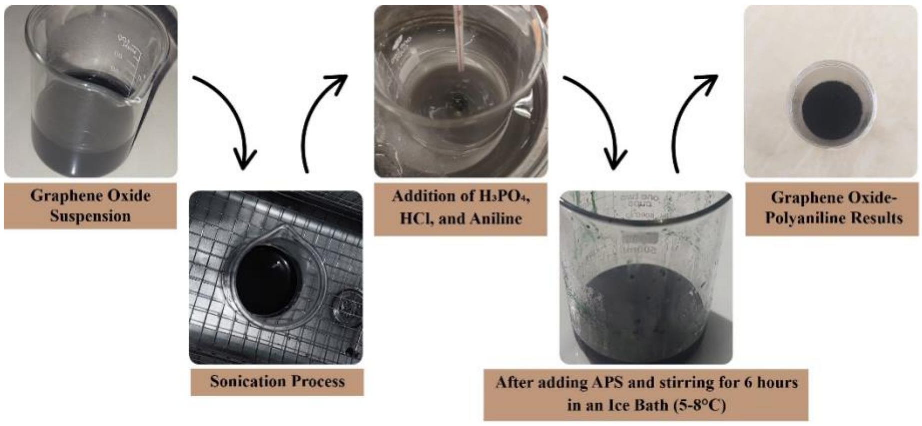


Figure 3. GO-PANI synthesis process

The experimental results described above were then integrated into an instructional tool, namely a student worksheet. This stage constitutes the development phase, which focuses on the preparation of a student worksheet adopting guided inquiry-based learning, in alignment with the experimental design previously conducted. In this phase, the researcher designed the student worksheet along with its assessment grid and rubric to evaluate the feasibility and effectiveness of the product.

Guided inquiry-based learning typically consists of six stages: presenting the problem orientation, formulating the problem, developing hypotheses, conducting experiments/exploration, analyzing data, and drawing conclusions (Fitri & Fatisa, 2019).

However, in the development of the student worksheet in this study, the researcher added an additional stage—collecting experimental data—placed after the experimentation and before data analysis. This additional stage was intended to provide students with explicit space to record, organize, and document their observations before proceeding to the analysis stage. The goal is to promote a more systematic and structured scientific thinking process among students, thereby enhancing the accuracy of their conclusions.

At the beginning section of the student worksheet, information is presented including the worksheet identity, the title of the practicum activity, course learning outcomes (CPMK), learning objectives, and instructions for using the worksheet. This information is intended to provide students with an initial orientation before engaging in the inquiry-based activity. The layout also features icons, supporting illustrations, and an attractive design to enhance students' learning motivation. The initial display of the student worksheet is shown in **Figure 4**.

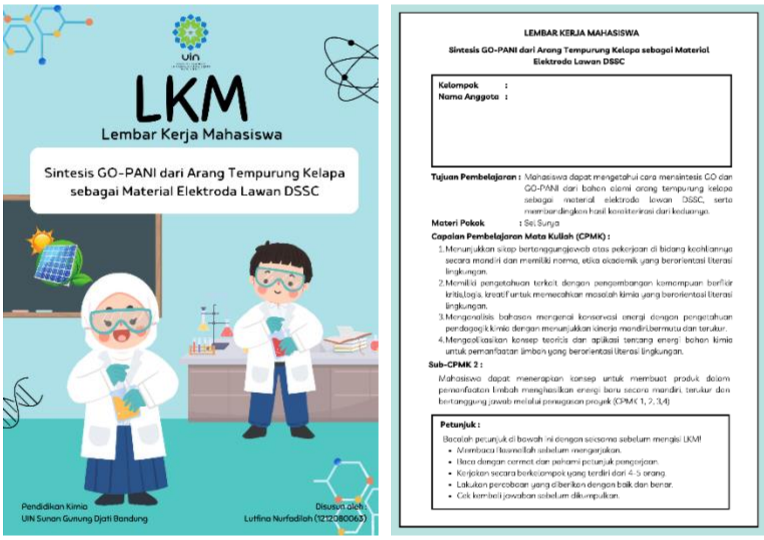


Figure 4. Initial display of the student worksheet

The first stage of the student worksheet is problem orientation. Students are introduced to global issues related to the importance of developing renewable energy, particularly solar energy. A reading passage is presented under the title "Utilization of GO-PANI from Coconut Shell Charcoal as a Counter Electrode Material for DSSCs." This passage discusses the limitations of conventional electrode materials such as platinum, which are expensive and not environmentally friendly, thus highlighting the need for alternatives based on local materials such as GO-PANI derived from coconut shell charcoal. In this stage, students are expected to analyze and identify the main ideas from the given passage and write them down in the worksheet.

The second and third stages involve formulating the problem and developing a hypothesis. Students are asked to identify a problem based on the previous reading passage. They are expected to state the problem that will be addressed in the GO-PANI synthesis experiment. This is followed by formulating a hypothesis or prediction aligned with the identified problem.

The fourth stage is designing the experiment. In this stage, a description of the procedural steps for the synthesis of GO and GO-PANI, based on the previously developed experimental design, is presented and illustrated in **Figure 5**. Students are required to determine the objective of the experiment, identify the equipment and materials needed, and construct a flowchart of the experiment based on the given procedural description. The indicators at this stage include the ability of students to design an experimental procedure based on the provided step-by-step description.

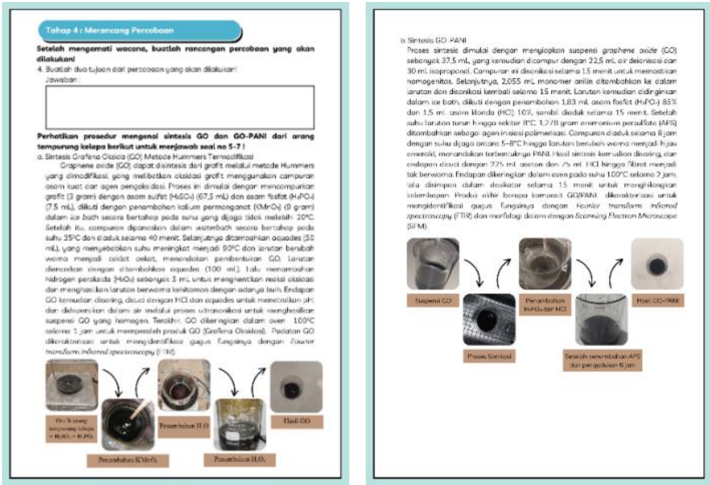

Figure 5. Experimental design phase in the student worksheet

In the fifth stage, students collect data by recording the experimental results in an observation table. The fourth and fifth stages help develop scientific performance skills such as designing, implementing, and conducting systematic observations, enabling students to actively engage in scientific thinking processes similar to those of a scientist. These activities also foster accuracy, consistency, and analytical abilities in the learning process.

The sixth stage involves data analysis. Students evaluate the experimental data and relate it to relevant chemical concepts. At this stage, six data analysis questions are presented, beginning with an analysis of each experimental step, followed by the interpretation of FTIR and SEM characterization data for the synthesized GO and GO–PANI samples. The indicators for this stage include students' ability to analyze FTIR spectra and SEM images to identify differences between pure GO and GO–PANI, as well as to evaluate the success of the synthesis and the functional interactions between materials based on literature references and surface morphology. Examples of the analysis questions are shown in **Figure 6.**

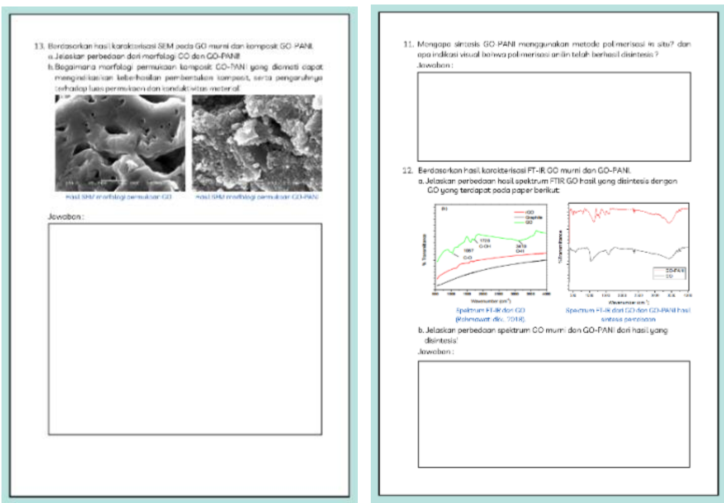

Figure 6. Experimental data analysis phase in the student worksheet

The final stage is drawing conclusions. In this stage, students reflect on their findings and compare them with the initial hypotheses. They then formulate conclusions based on the experimental results and data analysis.

Following the implementation of the learning process, the developed student worksheet underwent a validation process conducted by three Chemistry Education lecturers. Two of them specialize in chemistry content and evaluated the clarity and relevance of the material, while the third specializes in educational design and assessed pedagogical alignment and instructional effectiveness. The results showed that most indicators had an r value > 0,78, with an average r value of 0.94 (r table = 0,3) indicating a range from valid to highly valid. Three indicators received an r value of 1.00, while the other two—sentence clarity and availability of equipment—obtained r = 0.78 and were still considered valid. A visualization of the results is presented in **Figure 7**. Overall, the worksheet was deemed feasible for further development.

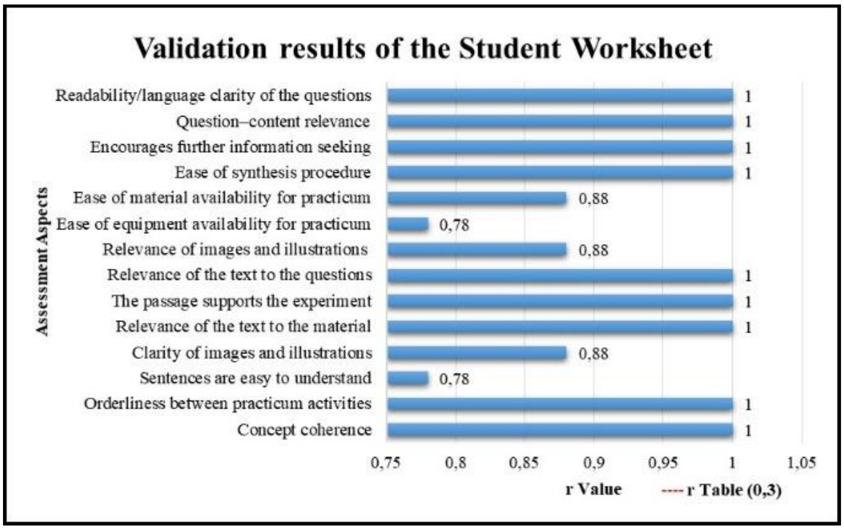


Figure 7. Bar chart of the student worksheet validity test results

The feasibility test of the student worksheet was conducted by 10 Chemistry Education students enrolled in the Energy Conservation course. Based on the assessment results, most indicators received a percentage score above 90%, with an average score of 92.2%, classified as "highly feasible." Meanwhile, two indicators—"easily understood sentences" and "experience in discovering concepts"—received scores of 86%, falling into the "feasible" category. The complete feasibility test results are presented in **Figure 8**, which illustrates students' responses to each evaluated aspect. These findings indicate that the worksheet is not only scientifically valid but also considered practical and easy to use by students. Therefore, the guided inquiry-based worksheet can be effectively implemented in experiment-based energy conservation learning.

With the validated and feasible student worksheet, along with the successful design of the experiment for synthesizing GO–PANI materials from coconut shell charcoal, it can be concluded that the experimental design is not only content-relevant but also effective for educational implementation. This is supported by the high feasibility ratings obtained in the validation stage—such as 96% for "instructions ease," which indicates clarity in guiding student procedures, and 93% for "concept discovery facilitation," which reflects the worksheet's ability to promote meaningful learning. These findings demonstrate that chemistry learning can be meaningfully integrated with issues of energy sustainability and advanced material development, while also providing students with opportunities to practice scientific and critical thinking through contextual laboratory activities.

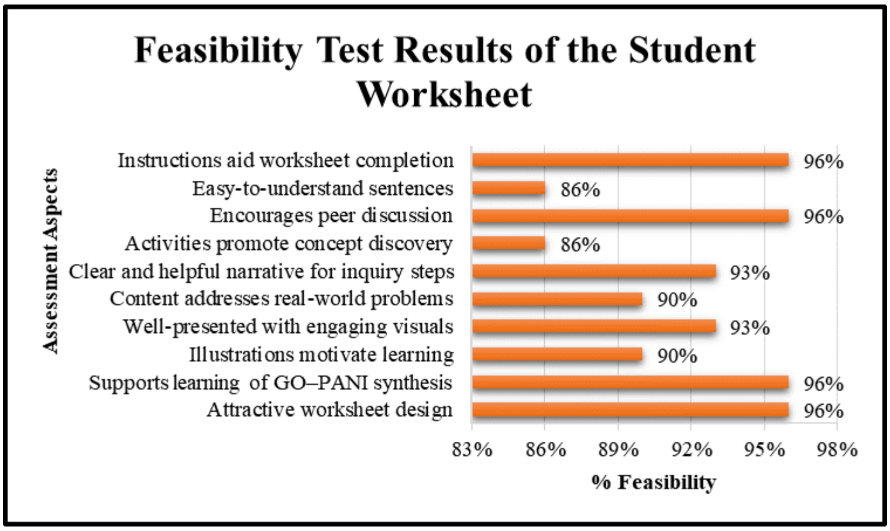


Figure 8. Bar chart showing the feasibility test results

## Conclusion

The experimental design for the synthesis of GO–PANI from coconut shell charcoal is valid and feasible for use in chemistry learning, supported by a guided inquiry-based Student Worksheet as an instructional tool. The development was informed by a preliminary needs analysis, which highlighted the lack of contextual lab activities integrating sustainability and advanced materials. Expert validation showed all aspects were rated very valid ($r \geq 0.78$), while the student feasibility test yielded scores above 90%, including 96% for instructional clarity and 93% for concept discovery facilitation. The synthesis procedure of GO–PANI via the modified Hummers method and in situ polymerization was found to be effective and implementable within student laboratory activities. These findings indicate the worksheet's effectiveness in promoting student engagement, conceptual understanding, and scientific skills through active inquiry. This study offers practical and relevant instructional materials for sustainability education. Future research may implement the worksheet more broadly and adapt it to similar experiments based on local resources, while also exploring its long-term impact on student learning outcomes.

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