



EXAMINING STUDENTS' PROCEDURAL SKILLS THROUGH THE CONSTRUCTION OF AN ELECTROSCOPE IN ELECTROSTATICS INSTRUCTION

Iin Suminar^{1*}, Mochammad Irfan Noviana², & M. Reza Dwi Saputra³

^{1&3}Physics Education Study Program, Faculty of Mathematics and Natural Sciences Education, Indonesian University of Education, Dr. Setiabudi Street Number 229, Bandung, West Java 40154, Indonesia

²Taruna Bakti Junior High School, LLRE Martadinata Street Number 52, Bandung, West Java 40115, Indonesia

*Email: iinsuminar28@upi.edu

Submit: 20-06-2025; Revised: 30-06-2025; Accepted: 03-07-2025; Published: 14-07-2025

ABSTRACT: The aim of this study is to examine students' procedural skills engagements through a low-tech, hands-on physics experiments involving the construction of an electroscope during electrostatics instruction. A total of 27 students, organized into eight collaborative groups, participated in the activity, which emphasized student autonomy in selecting materials, designing components, and performing technical adjustments such as stripping wire insulation. Adopting a descriptive qualitative approach, data were collected through classroom observations and assessed using a rubric that measured four key dimensions: material preparation, following the steps of the experiment, problem-solving and troubleshooting, and observational skills and interpretation. The results indicate that the majority of student groups demonstrated proficient to exemplary performance across most dimensions, particularly in material handling and interpreting experimental outcomes. These findings underscore the educational value of analog experimentation in fostering students' procedural competencies, supporting hands-on engagement, and reinforcing foundational scientific practices in a digitally evolving classroom environment.

Keywords: Electroscope, Hands-on Learning, Low-Tech Experiments, Procedural Skills.

How to Cite: Suminar, I., Noviana, M. I., & Saputra, M. R. D. (2025). Examining Students' Procedural Skills through the Construction of an Electroscope in Electrostatics Instruction. *Panthera : Jurnal Ilmiah Pendidikan Sains dan Terapan*, 5(3), 452-465. <https://doi.org/10.36312/panthera.v5i3.573>



Panthera : Jurnal Ilmiah Pendidikan Sains dan Terapan is Licensed Under a CC BY-SA Creative Commons Attribution-ShareAlike 4.0 International License.

INTRODUCTION

In science education, hands-on experiments have long been recognized as an essential tool for engaging students and enhancing their understanding of complex scientific principles (Schwchow et al., 2016; Sotiriou & Bogner, 2015). This is especially true in physics, where abstract concepts such as electrostatics can be difficult for students to visualize. One effective solution to this challenge is the use of low-tech, analog experiments, such as the construction of an electroscope. This simple, yet powerful device enables students to detect electrical charges, offering a practical and tangible means of exploring the principles of electrostatics. Unlike digital tools, the analog nature of the electroscope allows students to engage directly with the physical world, making abstract concepts more comprehensible.



Recent studies have highlighted the increasing reliance on digital technologies in modern classrooms, including the use of simulations and virtual labs to teach complex scientific principles (Haleem et al., 2022; Liu et al., 2015). While these technologies offer convenience and interactivity, several scholars argue that the use of analog tools-especially in subjects like physics-remains crucial for developing procedural skills (Kotsis, 2024; Pols & Dekkers, 2024; Vergis, 2025). Analog tools, such as the electroscope, provide an opportunity for students to engage more deeply with the scientific process by requiring them to make hands-on decisions, troubleshoot, and observe real-world outcomes. This contrasts with digital simulations, which often reduce the need for direct interaction with physical materials and the problem-solving process. Studies by Kotsis (2024) have emphasized that hands-on, experiments provide students with practical experiences that develop their critical thinking abilities and enhance their comprehension of scientific ideas. Despite these findings, the integration of low-tech experiments in classrooms has been underexplored, particularly in the context of developing procedural understanding.

Procedural understanding comprises students' knowledge of scientific methods such as designing and conducting experiments as well as their awareness of the strengths, limitations, and reasoning processes involved in scientific inquiry (Arnold et al., 2023). In the context of this study, procedural understanding was operationalized through a procedural skills rubric that assessed four key dimensions relevant to the construction of the electroscope: material preparation following the steps of the experiment, problem-solving, and observational skills. Each of these dimensions reflects a practical aspect of scientific method application. For example, material preparation relates to planning and organizing tools and variables, following experimental steps reflects students' ability to implement a structured procedure, problem-solving indicates their capacity to adapt and troubleshoot experimental challenges, and observational skills encompass the ability to analyze phenomena and interpret outcomes. Together, these components represent core aspects of procedural knowledge and serve as tangible indicators of students' engagement with the nature and process of science.

This article addresses a gap in the literature by exploring how analog experiments, specifically electroscope construction, can effectively develop procedural skills among junior high school students. While previous research has discussed the importance of hands-on learning and scientific reasoning, this study introduces a novel perspective by focusing on the self-directed nature of the electroscope experiment. In this experiment, students make their own decisions regarding the materials and design of the electroscope, which fosters independent problem-solving and deeper engagement with the scientific process. The novelty of this study lies in its emphasis on the practical application of analog technology in modern classrooms and its impact on developing critical procedural skills.

This study is guided by the following research question: "How do junior high school students demonstrate procedural skills such as material preparation, procedural execution, problem-solving, and observational interpretation during a hands-on electroscope construction activity in electrostatics instruction?". The aim of this study is to examine students' procedural skills engagements through a low-



tech, hands-on physics experiments involving the construction of an electroscope during electrostatics instruction. By documenting students' actions and choices during the task, this research contributes to a deeper understanding of how low-tech, hands-on physics experiments can reveal aspects of scientific practice.

METHOD

This study employed a descriptive qualitative approach to examine students' procedural skills as demonstrated through the construction of an electroscope used as a low-tech, analog tool during electrostatics instruction in junior high school. A total of 27 students, aged 14-15 years old, participated in the activity, which was conducted over one week as part of the regular physics curriculum. The study focused on observing students' engagement in experimental procedures, material handling, problem-solving, and interpretation, without the use of pre- or post-assessments. Classroom observations were conducted in real time using a structured checklist aligned with the four rubric dimensions by two observers. The checklist included observable indicators for each procedural skill, along with space for open-ended narrative comments. The observers recorded notes during the activity to capture students' actions, decision making process, and collaborative behaviour. To strengthen the credibility of the observations, the field notes were later triangulated with photo documentation of the construction process and samples of student work. Data were collected through classroom observation and the analysis of student work samples using a procedural skills rubric.

For the purpose of the experiment, students were divided into 8 groups, with each group consisting of 3 to 4 students. This collaborative setting encouraged discussion, role distribution, and peer-supported problem-solving throughout the electroscope construction process. Each group was provided with a basic set of materials such as aluminum foil, a glass jar, a paper clip, and a rubber stopper along with written instructions outlining the construction steps.

Students were tasked with building a functioning electroscope using simple, accessible materials such as aluminum foil, copper wire, plastic straws, glass jars, electrical tape, and common tools including scissors, pliers, and drills. While a worksheet provided general guidance on the experimental goals, students were encouraged to make independent decisions about how to shape the wire, select component lengths, or strip insulation from the copper wire an essential step to ensure electrical conductivity. This self-directed approach allowed students to demonstrate their procedural knowledge through both planning and improvisation.

The data collection focused on assessing students' procedural skills, using two primary methods: direct classroom observation and a procedural skills rubric. The procedural skills rubric used in this study was adapted from established frameworks in science education, particularly those emphasizing scientific thinking as a core competence. The model illustrated in Figure 1 guided the identification of key procedural aspects relevant to hands-on experiments work. Scientific thinking, as outlined in the framework, is composed of three primary sub-competences: generating hypotheses, designing experiments, and analyzing data, each supported by specific cognitive and procedural components.

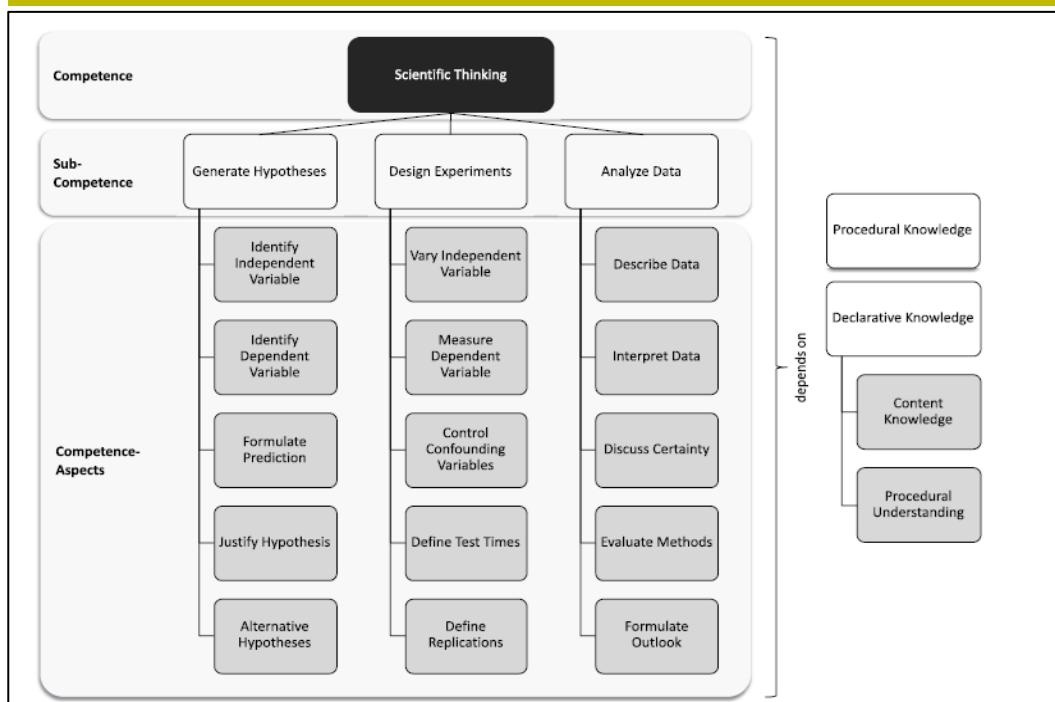


Figure 1. Scientific Thinking and its Sub-Competences (Arnold et al., 2023).

While not all aspects of the broader scientific competence model directly applied to the electroscope construction task, the rubric was intentionally designed to capture the practical manifestations of key sub-competences within the context of a junior high school physics activity. Four core dimensions were derived and operationalized in the rubric, as outlined in Table 1.

Table 1. Four Key Dimensions as Framework of Procedural Skills.

Dimension	Description
Material Preparation	This dimension reflects students' ability to plan and organize the resources needed for experimentation. Within the framework, this aligns closely with aspects of generating hypotheses, particularly in identifying variables (e.g., independent and dependent variables) and formulating predictions.
Following the Steps of the Experiment	This dimension is rooted in the design experiments domain of the framework. It reflects the students' capacity to follow a logical and ordered sequence of actions similar to varying independent variables, defining test times, or measuring dependent variables.
Problem-Solving and Troubleshooting	This dimension relates to how students recognize and respond to challenges during experimentation. It draws upon multiple elements within the design experiments strand, especially controlling confounding variables and defining replications.
Observational Skills and Interpretation	This dimension parallels the analyze data category in the framework, particularly in the aspects of describing data, interpreting data, and evaluating methods.

The procedural skills rubric was developed based on four key dimensions which were adapted from relevant aspects of the scientific thinking framework (Arnold et al., 2023) and validated through expert review by two science



educators. The four key components assessed in the rubric are shown in Table 2 below.

Table 2. Four Key Components of Procedural Skills.

Criteria	Description	Score 1 (Needs Improvement)	Score 2 (Developing)	Score 3 (Proficient)	Score 4 (Exemplary)
Material Preparation	Ability to prepare and organize the necessary materials for the experiment efficiently and effectively.	Struggled to gather or organize materials.	Gathered materials but required more organization.	Organized materials well and used them appropriately.	Prepared and organized materials efficiently and effectively.
Following the Steps of the Experiment	Ability to follow the given steps for constructing the electroscope, including correct assembly and completion of each stage.	Struggled to follow steps; needed significant guidance.	Followed steps partially; required some assistance.	Followed steps with minimal errors.	Followed all steps independently and with exceptional detail.
Problem-Solving and Troubleshooting	Ability to troubleshoot issues during construction, identify problems, and take corrective actions independently or with minimal assistance.	Had difficulty identifying and solving problems.	Resolved some problems with guidance.	Troubleshooted and resolved issues independently with minor errors.	Diagnosed and resolved all problems independently and with high accuracy.
Observational Skills and Interpretation	Ability to observe the behavior of the electroscope, identify movements in the aluminum foil, and accurately interpret the results based on electrostatics.	Had difficulty observing or interpreting the electroscope behavior.	Observed and interpreted some behavior but lacked full understanding.	Accurately observed and interpreted most behaviors.	Observed and interpreted behaviors in great detail with full understanding.

Throughout the activity, the classroom teacher functioned as both facilitator and observer. Students were given the opportunity to work independently in their groups, with the expectation that they would make their



own decisions regarding materials, construction design, and problem-solving strategies. The teacher provided support only when groups encountered persistent difficulties that could not be resolved through peer discussion. This included brief interventions such as clarifying instructions, guiding questions, or technical safety advice especially when students misused tools or struggled to detect charge due to overlooked details.

Data analysis was conducted by examining the quantitative data collected from the rubric. Rubric scores were summarized using descriptive statistics to identify trends in students' procedural skills. Qualitative insights were drawn from representative student work samples, which helped contextualize the rubric results and highlight how students demonstrated procedural skills in the construction process.

RESULT AND DISCUSSION

The assessment of procedural skills was conducted at the group level, as students completed the electroscope construction in 8 collaborative teams of 3 to 4 students each. Data were gathered through direct observation and rubric-based scoring during the activity. The analysis focused on four main indicators: material preparation, following experimental steps, problem-solving and troubleshooting, and observational skills and interpretation.

To further illustrate the development of students' procedural skills, selected samples of student work were analyzed in relation to the procedural skills rubric outlined in Table 2. In the material preparation phase, students demonstrated autonomy in selecting materials based on functionality and availability. Each group independently chose the diameter of the copper wire they considered most suitable for constructing the electroscope's internal conductor. Some groups preferred thinner wire for ease of bending, while others selected thicker wire for structural stability. Additionally, students made decisions about the type of container used either plastic or glass jars and the corresponding lid material, evaluating factors such as lid flexibility, ease of drilling, and stability when supporting the internal structure. These decisions, though seemingly minor, reflected the students' ability to consider practical constraints and functional needs, indicating engagement in procedural planning.

The student carefully documented each phase of the electroscope construction process, including shaping the copper wire, attaching the aluminum foil, and performing the final assembly. The sequence of actions was logical and coherent, demonstrating a clear understanding of procedural flow and the mechanical structure of the device. This performance indicates that the student was able to follow experimental steps accurately, adapt the instructions to real-world conditions, and complete the task with minimal need for correction. The student's meticulous attention to detail throughout the process reflects strong observational and problem-solving skills. For instance, the proper alignment of components and secure attachment of conductive materials suggest not only technical competence but also an awareness of the electroscope's functional requirements. This level of execution reflects proficiency in following the steps of the experiment, as illustrated in Figure 2.

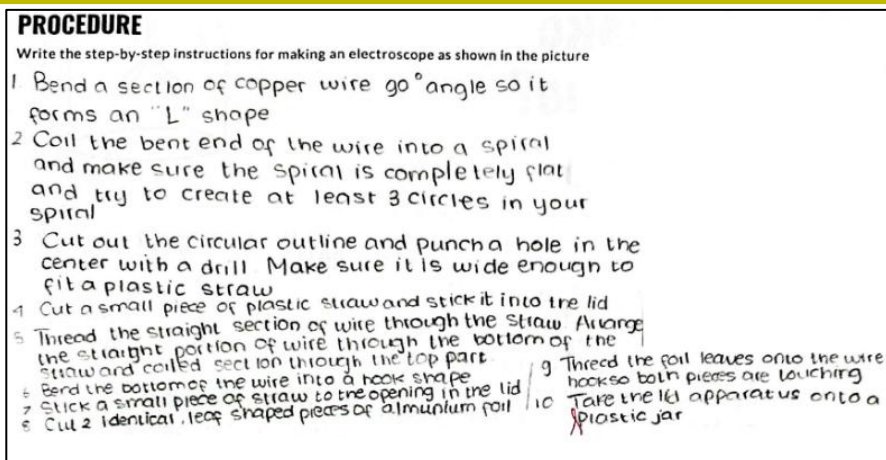


Figure 2. Following the Steps of the Experiment.

The student's ability to follow procedures independently and adjust them based on situational needs reflects a core aspect of procedural understanding in science education. According to Pols & Dekkers (2024), the ability to translate written instructions into physical actions is a hallmark of meaningful practical work. Similarly, Vorholzer et al. (2020) argue that well-structured hands-on tasks promote students' procedural fluency and allow them to connect abstract procedures with tangible outcomes. In this case, the student's execution of each stage of the task indicates not only task compliance, but also procedural autonomy an essential outcome of inquiry-based science learning.

Building on their understanding of the electroscope's structure, students also demonstrated reasoning related to its functional design. In response to the question "Why is the wire of electroscope formed into a spiral?", one student offered an explanation that showed awareness of how specific design choices can affect the sensitivity and performance of the instrument. Additionally, during the construction process, several groups took the initiative to strip the insulation coating from the copper wire to ensure proper electrical contact between components an action not explicitly required in the instructions. This decision reflects not only functional understanding but also adaptability and initiative in refining their experimental design. These behaviors provide strong evidence of students' engagement in Problem-Solving and Troubleshooting, as illustrated in Figure 3.

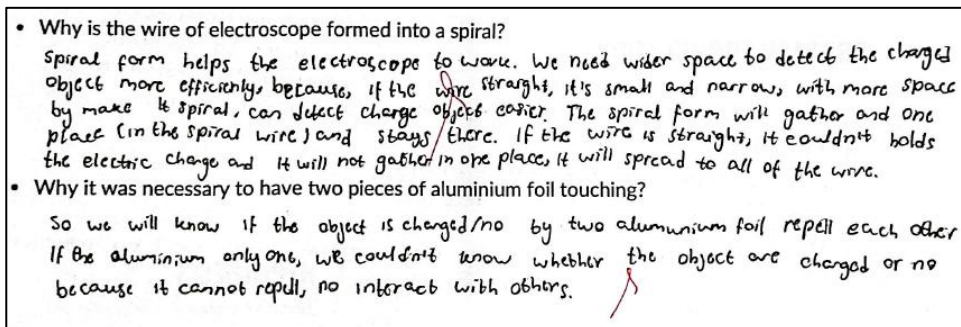


Figure 3. Problem-Solving and Troubleshooting.

These findings indicate that students did not merely follow instructions, but actively interpreted the function of each component and made informed design decisions. The act of modifying the copper wire reflects a form of procedural knowledge an essential part of scientific thinking (Arnold et al., 2023). This aligns with Kotsis (2024) findings that student-led inquiry can foster deeper engagement in the scientific process, including hypothesis testing and experimental refinement. Similarly, Aldosari & Alsager (2023) emphasized that giving students autonomy in practical tasks encourages them to think critically and respond to problems creatively. The spontaneous decision to remove wire insulation also illustrates students' intuitive understanding of electrical conductivity, a concept often considered abstract at the junior high school level. This echoes Arnold et al. (2023), argument that hands-on experimentation supports the development of integrated conceptual and procedural knowledge in science education.

The final student work sample demonstrates the student's ability to describe the behavior of the electroscope when influenced by a charged object. The student accurately observed the separation of the aluminum foil leaves and related this phenomenon to the principle of electrostatic induction, indicating a solid grasp of the underlying concept. In addition to written explanations, several groups supplemented their responses with diagrams that illustrated how the foil leaves reacted as the charged object approached. These visual representations helped clarify their interpretations and showed their ability to conceptualize and communicate abstract phenomena through representational thinking. This performance aligns with the criteria for observational skills and interpretation, as demonstrated in Figure 4.

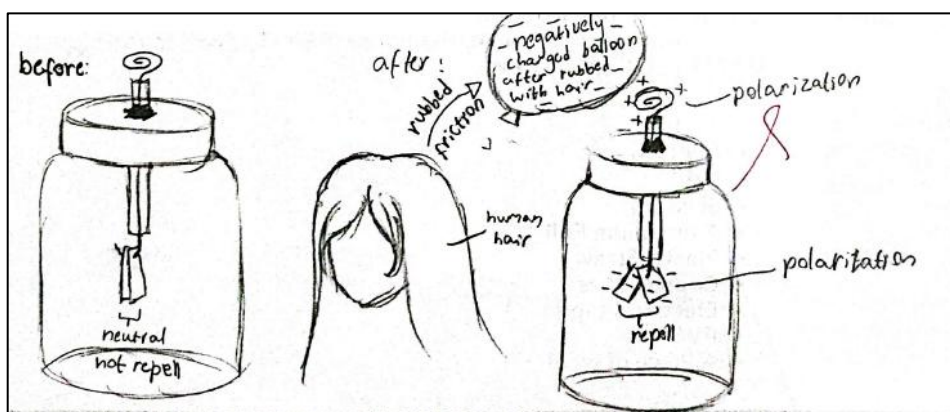


Figure 4. Observational Skills and Interpretation.

These results indicate that students were not only able to observe and describe physical outcomes, but also to construct representational meaning from abstract concepts. The inclusion of diagrams illustrates the use of representational thinking a skill linked to deeper conceptual understanding (Suminar et al., 2025). As supported by Kotsis (2024), student-centered, hands-on activities promote active engagement in scientific reasoning, including interpreting phenomena based on evidence. This approach builds understanding by engaging students in inquiry and critical thinking through real scientific activities.

To complement the rubric-based evaluation and deepen the understanding of how procedural skills were demonstrated, documentary evidence of student activity was also collected. Observing students in action provided insights not only into the outcomes of their work but also into the practical decisions, tool usage, and collaborative interactions that occurred throughout the task. The following figure presents a visual snapshot of these key moments during the hands-on construction process.



Figure 5. Hands-on Construction Process.

Figure 5 captures key moments of the electroscope construction process conducted by the students. The images show students using a hand drill to create a hole in the jar lid, stripping the copper wire with pliers to remove insulation, cutting aluminum foil with scissors to prepare the sensitive leaf component of the electroscope.

These steps visually demonstrate students' engagement with material preparation, tool usage, and practical decision-making, reflecting procedural competencies described in the rubric. The careful manipulation of tools and materials confirms that students not only followed the construction steps but also exhibited mechanical precision, coordination, and team collaboration. These observations further support the rubric assessment results, particularly in the domains of Material Preparation, Problem-Solving, and Following Steps of the Experiment. Their ability to manipulate tools accurately, collaborate with peers, and adapt construction steps indicates more than simple task completion; it shows developing competence in mechanical reasoning and procedural autonomy. These findings are in line with previous research by Dewi & Safnowandi (2020) and Gnesdilow & Puntambekar (2022), which emphasized that laboratory tasks involving physical construction enhance students' motor coordination, problem-solving skills, and understanding of scientific tools. Similarly Kapici et al. (2019), highlighted that procedural understanding emerges when students engage with real tools in authentic problem-solving contexts.

To provide a clearer overview of how each group performed across the different procedural skill components, the results of the rubric-based assessment have been summarized in the following bar chart. This visual representation illustrates the distribution of scores ranging from developing to exemplary for all eight student groups. The bar chart clearly compares performance levels, showing which procedural skills were more challenging and which were consistently well-mastered. Categorizing scores into four tiers developing, satisfactory, proficient, and exemplary helps highlight trends in student achievement. This visual representation aids in quickly identifying areas needing improvement.

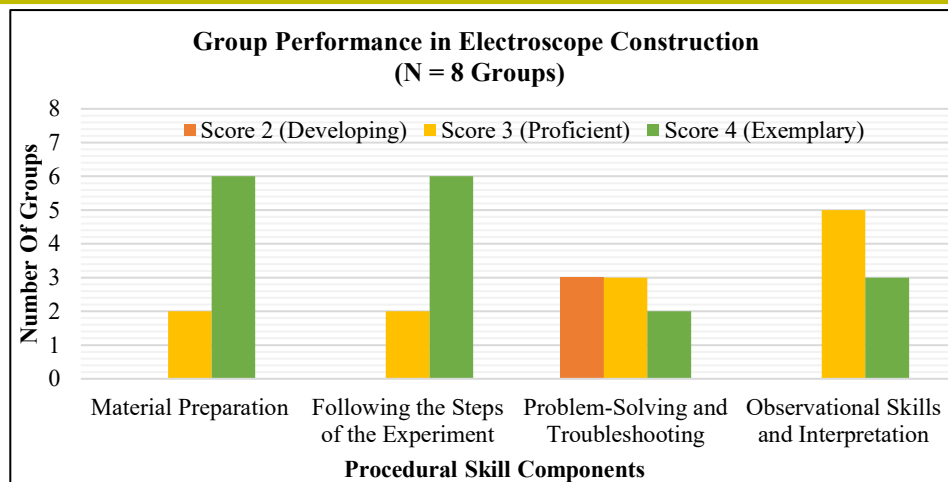


Figure 6. Group Performance in Electroscope Construction.

The bar chart in Figure 6 presents the distribution of scores achieved by the eight student groups across the four procedural skill dimensions. A closer examination reveals that six out of eight groups scored ‘exemplary’ or higher in material preparation and in following the steps of the experiment. This suggests that most groups demonstrated strong procedural adherence, effectively organizing materials, assembling components, and completing the construction of the electroscope in a logical and systematic manner. In the problem-solving and troubleshooting dimension, five out of eight groups demonstrated independent problem-solving (Proficient and Exemplary), although three groups still required teacher assistance, indicating variability in students’ capacity to independently identify and resolve construction challenges. While some groups were able to make effective adjustments such as stripping wire insulation to ensure conductivity others required teacher support to address issues like unstable structures or weak charge detection. Notably, three out of eight groups scored ‘exemplary’ in observational skills and interpretation. These groups demonstrated not only documented the physical response of the electroscope accurately but also enhanced their work by incorporating visual diagrams to represent the movement of electric charges and the separation of foil leaves in relation to the proximity of a charged object. This integration of representational thinking further underscores their conceptual understanding and procedural sophistication. These quantitative patterns reinforce the overall observation that students were actively engaged and capable of applying procedural thinking across multiple aspects of the activity.

These samples validate the rubric’s effectiveness in capturing students’ procedural skills and demonstrate how analog, low-tech experimentation can foster deep engagement with scientific practices (Kapici et al., 2019; Tindan & Anaba, 2024). Through these tasks, students not only applied theoretical knowledge but also refined essential skills that underpin experimental physics. Furthermore, these findings are in line with research on STEM-integrated and project-based learning approaches, which emphasize the importance of engaging students in designing, constructing, and iterating physical models to develop both conceptual and procedural understanding (Anugrah et al., 2023; Belbase et al.,



2022; Diana et al., 2021; Probowati et al., 2020; Sucilestari et al., 2023; Wulandari et al., 2024; Yanti et al., 2023). In such contexts, students are encouraged to solve real-world problems, make decisions about tools and materials, and reflect on outcomes behaviors that were also evident during the electroscope construction. Through these hands-on activities, learners not only apply theoretical concepts, but also build critical scientific skills, such as precision, collaboration, and iterative problem-solving, which are foundational to experimental physics.

In conclusion, the study demonstrates that constructing an electroscope as a low-tech, analog experiment is a powerful tool in developing students' procedural skills in a physics classroom. While most students successfully followed the steps and demonstrated strong problem-solving abilities, the study also underscores the need for continued teacher support in helping students refine these skills, particularly in troubleshooting and applying theoretical concepts. These findings highlight the ongoing relevance of analog technologies in fostering critical thinking and hands-on learning in science education, even in an increasingly digital age.

CONCLUSION

This study demonstrates that constructing an electroscope as a low-tech, analog experiment is effective in enhancing junior high school students' procedural skills. By allowing students to independently determine the materials and design of their electroscope, the activity fostered critical aspects of scientific practice, such as following structured procedures, preparing experimental materials, problem-solving during construction, and interpreting experimental outcomes.

The majority of students successfully exhibited these procedural competencies, particularly in preparing materials and interpreting results. The experiment encouraged active engagement, trial and error, and hands-on learning, which are essential elements of science education. Furthermore, the analog nature of the task provided meaningful interaction with physical phenomena, which digital simulations alone may not fully replicate.

The findings of this study highlight the continued relevance of analog tools in the physics classroom, particularly as a means to support the development of students' procedural thinking and practical experimentation skills. In the context of growing digitalization, such low-tech, high-impact activities offer valuable balance and reinforce foundational scientific habits. Future research may further explore how variations in analog experiment design affect different dimensions of scientific literacy and skill development.

RECOMENDATION

The results of this study support the recommendation that educators integrate low-tech, analog experiments such as the construction of an electroscope into physics learning to enhance students' procedural skills. These experiments provide meaningful opportunities for students to actively engage in the scientific process through hands-on tasks that require independent decision-making,



problem-solving, and interpretation of real phenomena. Teachers are encouraged to design classroom activities that allow students to select materials and determine their own experimental approaches, as this autonomy can significantly improve procedural understanding. The use of structured assessment tools, such as the procedural skills rubric presented in this study (Table 1), is also recommended to monitor student progress and provide targeted support.

It is also recommended that educators create a classroom culture that embraces trial and error as a natural part of learning, allowing students to reflect on failures and refine their methods. For schools with limited access to technology, this approach presents a cost-effective and high-impact solution for improving scientific literacy. Future implementations may further enhance student outcomes by combining analog experiments with structured reflection and collaborative analysis, supporting both conceptual understanding and procedural competence.

While the findings of this study offer valuable insights, the scope was limited to a small group of students in a single school context. Broader implementation in diverse educational settings is needed to examine the generalizability of the results. For future research, studies could expand the sample across multiple school contexts and compare procedural skill development under varying instructional conditions (e.g., guided vs. open inquiry). Moreover, integrating analog experiments with structured student reflections, peer evaluation, or digital recording tools may provide richer data and support deeper insights into how students develop procedural competence over time. Longitudinal research may also be valuable in tracking how such low-tech practices influence students' scientific thinking beyond a single learning unit.

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to the students who participated in this study and demonstrated great enthusiasm throughout the electroscope construction activity. Special thanks are also extended to the science teacher who supported the implementation of this hands-on project, provided access to classroom resources, and assisted in the observation and assessment process.

REFERENCES

- Aldosari, M. S., & Alsager, H. N. (2023). A Step Toward Autonomy in Education: Probing into the Effects of Practicing Self-Assessment, Resilience, and Creativity in Task Supported Language Learning. *BMC Psychology*, 11(1), 1-20. <https://doi.org/10.1186/s40359-023-01478-8>
- Anugrah, A., Herlina, K., & Suyatna, A. (2023). Inquiry-Integrated STEM on Electronic Student Worksheet: An Effort to Stimulate Creative Thinking and Collaborative Skills. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, 12(2), 251-263. <https://doi.org/10.24042/jipfalbiruni.v12i2.17306>
- Arnold, J. C., Mühling, A., & Kremer, K. (2023). Exploring Core Ideas of Procedural Understanding in Scientific Inquiry Using Educational Data Mining. *Research in Science and Technological Education*, 41(1), 372-



392. <https://doi.org/10.1080/02635143.2021.1909552>

- Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022). At the Dawn of Science, Technology, Engineering, Arts, and Mathematics (STEAM) Education: Prospects, Priorities, Processes, and Problems. *International Journal of Mathematical Education in Science and Technology*, 53(11), 2919-2955. <https://doi.org/10.1080/0020739X.2021.1922943>
- Dewi, I. N., & Safnowandi, S. (2020). The Combination of Small Group Discussion and ARCS (MODis-ARCS Strategy) to Improve Students' Verbal Communication Skill and Learning Outcomes. *Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, 8(1), 25-36. <https://doi.org/10.33394/j-ps.v8i1.2478>
- Diana, N., Yohannes, Y., & Sukma, Y. (2021). The Effectiveness of Implementing Project-Based Learning (PjBL) Model in STEM Education: A Literature Review. *Journal of Physics: Conference Series*, 1882(1), 1-20. <https://doi.org/10.1088/1742-6596/1882/1/012146>
- Gnesdilow, D., & Puntambekar, S. (2022). Comparing Middle School Students' Science Explanations During Physical and Virtual Laboratories. *Journal of Science Education and Technology*, 31(2), 191-202. <https://doi.org/10.1007/s10956-021-09941-0>
- Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the Role of Digital Technologies in Education: A Review. *Sustainable Operations and Computers*, 3(1), 275-285. <https://doi.org/10.1016/j.susoc.2022.05.004>
- Kapici, H. O., Akcay, H., & Jong, T. D. (2019). Using Hands-on and Virtual Laboratories Alone or Together-Which Works Better for Acquiring Knowledge and Skills? *Journal of Science Education and Technology*, 28(3), 231-250. <https://doi.org/10.1007/s10956-018-9762-0>
- Kotsis, K. T. (2024). Significance of Experiments in Inquiry-Based Science Teaching. *European Journal of Education and Pedagogy*, 5(2), 86-92. <https://doi.org/10.24018/ejedu.2024.5.2.815>
- Liu, D., Díaz, P. V., Riofrio, G., Sun, Y. M., & Barba, R. (2015). Integration of Virtual Labs into Science E-learning. *Procedia Computer Science*, 75(1), 95-102. <https://doi.org/10.1016/j.procs.2015.12.224>
- Pols, C. F. J., & Dekkers, P. J. J. M. (2024). Redesigning a First Year Physics Lab Course on the Basis of the Procedural and Conceptual Knowledge in Science Model. *Physical Review Physics Education Research*, 20(1), 1-18. <https://doi.org/10.1103/PhysRevPhysEducRes.20.010117>
- Probowati, D., Iswari, R. S., & Sukaesih, S. (2020). The Influence of Project Based Creative Problem Solving Toward Creative Thinking Ability on Circulation System. *Journal of Biology Education*, 9(2), 167-177. <https://doi.org/10.15294/jbe.v9i2.22430>
- Schwichow, M., Zimmerman, C., Croker, S., & Härtig, H. (2016). What Students Learn from Hands-on Activities. *Journal of Research in Science Teaching*, 53(7), 980-1002. <https://doi.org/10.1002/tea.21320>
- Sotiriou, S., & Bogner, F. X. (2015). A 2200-Year Old Inquiry-Based, Hands-on



- Experiment in Today's Science Classrooms. *World Journal of Education*, 5(2), 52-62. <https://doi.org/10.5430/wje.v5n2p52>
- Sucilestari, R., Ramdani, A., Sukarso, A., Susilawati, S., & Rokhmat, J. (2023). Project-Based Learning Supports Students' Creative Thinking in Science Education. *Jurnal Penelitian Pendidikan IPA*, 9(11), 1038-1044. <https://doi.org/10.29303/jppipa.v9i11.5054>
- Suminar, I., Nurdini, N., Fratiwi, N. J., Abdurrahman, D., & Purwanto, M. G. (2025). Inquiry-Driven Essay Assessment (IDEA) as a Framework for Evaluating Students' Argumentation in Static Fluids. *Indonesian Journal of Science and Mathematics Education*, 8(1), 26-43. <https://doi.org/10.24042/ijsme.v8i1.26194>
- Tindan, T. N., & Anaba, C. A. (2024). Scientific Hands-on Activities and its Impact on Academic Success of Students: A Systematic Literature Review. *IOSR Journal of Research & Method in Education*, 14(6), 39-47. <https://doi.org/10.9790/7388-1406043947>
- Vergis, E. (2025). Reflections on the Role of Procedural Knowledge in the Teaching of Science. In Tippet, C. D., & Milford, T. M. (Ed.) *Handbook of Seeing Science through the Eyes of Canadian Teachers and Learners. Contemporary Trends and Issues in Science Education*. Cham: Springer Nature Switzerland.
- Vorholzer, A., Aufschnaiter, C. V., & Boone, W. J. (2020). Fostering Upper Secondary Students' Ability to Engage in Practices of Scientific Investigation: A Comparative Analysis of an Explicit and an Implicit Instructional Approach. *Research in Science Education*, 50(1), 333-359. <https://doi.org/10.1007/s11165-018-9691-1>
- Wulandari, N. O., Sutrio, S., Doyan, A., & Rahayau, S. (2024). The Influence of Project Based Learning Model on Creative Thinking Skills and Physics Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, 10(12), 10660-10669. <https://doi.org/10.29303/jppipa.v10i12.9738>
- Yanti, N., Rahmad, M., & Azhar, A. (2023). Application of PjBL (Project Based Learning) Based Physics Learning Model to Improve Collaboration Skills and Creative Thinking Ability of Students. *Jurnal Penelitian Pendidikan IPA*, 9(11), 9973-9978. <https://doi.org/10.29303/jppipa.v9i11.5275>