Research Article

# Fostering Scientific Attitudes Through Virtual Practicum: Exploring the Impact of PhET Interactive Simulations in Elementary Science Education

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**Abstract.**
This study investigates the effectiveness of online practicum activities utilizing PhET interactive virtual simulations in fostering scientific attitudes among 5th-grade elementary school students. Conducted using a quantitative descriptive approach, the research involved 100 students from a private elementary school in Bandung, Indonesia. Data collection instruments included a questionnaire to gauge students' perceptions of scientific attitudes in virtual practicums and an observation rubric based on video recordings to evaluate scientific attitudes displayed by students individually and in groups. Quantitative data were analyzed using SPSS 25, while video recordings were qualitatively analyzed to identify emerging aspects of scientific attitudes. The findings revealed that the highest perception scores for individual activities were observed in the aspects of curiosity (79.7), and honesty (80.25). Qualitative analysis of the practicum recordings indicated that the most prominent scientific attitude aspects exhibited by students working individually were accuracy, curiosity, responsibility, discipline, and honesty. These results suggest that online practicum activities supported by interactive PhET simulations effectively promote the development of scientific attitudes, making them a viable alternative for science learning in online education settings.

**Keywords:** elementary science education, virtual laboratory, scientific attitude

## 1. INTRODUCTION

In science education, students are not only expected to build and deepen their understanding through scientific activities but also to develop a *scientific attitude*—a mindset reflecting the habits of thinking characteristic of scientists (1). This attitude is cultivated not merely through reading textbooks or following teachers' instructions but through repeated engagement in scientific activities, with laboratory practicum being a central component. Practicum serve as a vital bridge between theory and reality, providing hands-on experience, fostering skills, enhancing conceptual understanding, and strengthening long-term memory retention (2,3). Furthermore, scientific activities significantly influence students' learning processes, shaping their attitudes, which are naturally developed by their environment. In general, practicum, laboratory work or another form of scientific activity is necessary to harmonize the cognitive, affective, and psychomotor aspects (4)

Practical work is employed to cultivate scientific attitudes among students; however, not all experiments can be conducted easily (5). The limited opportunities for in-person laboratory practicum have prompted educators to seek alternative solutions of equivalent quality. One such solution is the use of PhET interactive simulations, a virtual laboratory platform. These simulations not only offer "learning by doing" experiences but also allow students to access practical learning anytime and anywhere, both online and offline. PhET simulations bring several advantages: they ensure safe practical interactions, increase interest in science, enable direct engagement with abstract concepts, and help students connect with the material being studied (2,3,5–8). Students who have high scientific attitude will achieve satisfactory learning outcomes and always take full responsibility for doing all the things necessary for effective learning (9)

Virtual laboratories contribute significantly to distance learning through three key factors: providing direct experiential learning, fostering active cognitive engagement, and involving students in knowledge formation. These factors enhance students' abilities to design and plan experiments, develop practical laboratory skills, and practice essential scientific skills (6). Such experiential learning boosts motivation and cultivates scientific attitudes (3). The virtual laboratory offers exciting lab processing and simulation facilities, the ease of use of tools, and more accurate results (2). Through the virtual lab activity, the students have the opportunity to repeat the wrong experiment and deepen the experience independently. However, distance learning has faced criticism for potentially lowering motivation among both students and teachers, as many educators perceive face-to-face learning to be more effective. Yet, the success of distance science education hinges on fostering scientific attitudes, which play a critical role in both learning processes and outcomes.

Scientific attitude reflects students' perspectives and approaches to learning, influencing their acceptance or rejection of particular methods. Five core aspects consistently serve as indicators of scientific attitude: curiosity, responsibility, honesty, discipline, confidence, and accuracy (2,10–13). These qualities are benchmarks for scientific rigor, essential in both practicum and other science-related activities. As noted by previous research, without a scientific attitude, practicum findings may lack accountability (10), Another study indicates that poorly developed scientific attitudes can reduce students' enthusiasm for learning science (11). Scientific attitudes encompass a blend of qualities and virtues that manifest in an individual's behavior.

Given this context, the present study aims to examine the potential of virtual laboratories in fostering scientific attitudes during asynchronous learning. The findings are expected to offer valuable insights for teachers, parents, and education practitioners, enabling them to design diverse and meaningful learning activities that continue to engage students and develop their scientific competencies effectively.

## 2. METHODOLOGY

This study employed a descriptive quantitative research design to comprehensively describe and explore the emergence of scientific attitude aspects in online activities conducted in virtual laboratories using interactive Physics Education Technology (PhET) simulations for 5th-grade elementary school students. The sample consisted of 100 fifth-grade students from a private elementary school in Bandung, Indonesia. Probability sampling was used to select participants, excluding those who did not fully submit the required data.

Data collection involved two primary methods: 1) Practicum Screen Recordings: Students' virtual practicum sessions, supported by PhET interactive simulations, were recorded and analysed qualitatively to identify specific scientific attitude aspects exhibited during the activities. 2) Questionnaires: A Likert-scale questionnaire was administered to capture students' perceptions of scientific attitudes. The instrument comprised indicators developed based on indicators of scientific attitudes synthesized from several previous studies focusing on elementary school students' scientific attitudes. The indicators were curiosity, responsibility, discipline, honesty, and accuracy. The indicators were then formulated into statements, which students were asked to evaluate based on their perceptions. Students rate their perception ranging from 1 ("strongly disagree") to 4 ("strongly agree"), as a post test.

The reliability of the questionnaire was tested using SPSS 25, yielding a Cronbach's alpha score of 0.873, indicating a high level of reliability. Out of the initial 100 students, only 53 provided complete and usable data, as 46 participants did not submit the required instruments in their entirety. Consequently, the final analysis was conducted on the data from these 53 students. This methodology provided a robust framework for identifying and analysing the emergence of scientific attitude aspects in virtual practicum activities. This is particularly evident in virtual learning activities that utilize the internet as a learning resource, where the temptation to search for other, more appealing content tends to be greater, offering insights into the potential of interactive simulations in fostering such attitudes in elementary science education especially in virtual activity.

## 3. RESULTS AND DISCUSSIONS

To understand students' perceptions of scientific attitudes the collected questionnaire data was analyzed quantitatively with assistance from SPSS 25 software. The results are as follows.

TABLE 1: Descriptive Data Analysis.

| Aspects | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Curiosity | 53 | 79,7 | 26,15 | 5,1 |
| Responsibility | 53 | 66,65 | 31,25 | 6,05 |
| Discipline | 53 | 61 | 28,9 | 5,6 |
| Honesty | 53 | 80,25 | 24,8 | 4,8 |
| Accuracy | 53 | 65,05 | 28,4 | 5,5 |

The quantitative data analysis presented in the table above indicates that students exhibit high levels of curiosity and honesty when engaging in virtual practicums without a teacher's direct presence. Children are naturally drawn to the phenomena around them, observing and seeking explanations for their experiences. In this context, science learning supported by virtual practicums enables students to explore scientific concepts deeply, even at the molecular level, resulting in a more comprehensive learning process (12). Curiosity is demonstrated through a strong desire to understand new sensory experiences, attentive engagement, and a willingness to embrace unfamiliar situations. Meanwhile, the quest to expand knowledge (complexity) is reflected in activities such as interpreting, exploring, and navigating ambiguity (14). scientific experiments can be carried out by the students repeatedly, in their own time, at the place that is convenient for them that would make the students feel more comfortable to discover the scientific knowledge and expand their curiosity (15).

Additionally, when conducting virtual practicums independently, students tend to explore beyond the instructions provided in the worksheet without fear of the results' validity (11). This learning freedom in a non-pressured environment encourages students to utilize all their skills for exploration, leading to deeper, more thorough understanding and fostering more complex thinking processes (13,16). To better understand the scientific attitudes exhibited by students during asynchronous virtual practicums conducted at home, the recordings submitted to the researcher were analyzed qualitatively. The summarized findings are as follows:

Table 2: Qualitative Data Analysis.

| | |
|---|---|
| Curiosity | Students were enthusiastic about conducting the practicum and spent significant time to answer the questions in the module. |
| | They performed the practicum in multiple ways, not just following the module's instructions. |
| | Students explored every feature of the virtual practicum, even those not instructed in the module. |
| Responsibility | Students completed the worksheet in the module with diligence. |
| | They conducted the practicum seriously, adhering to the instructed steps. |
| | Students submitted the worksheet to the teacher as instructed. |
| Discipline | Students followed the rules during the practicum. |
| | They submitted the practicum report on time. |
| | They used their practicum time effectively and efficiently to answer the questions. |
| Honesty | Students provided proof of virtual laboratory activities that were genuinely their own. |
| | There was consistency between their worksheet results and the activities observed in the recording. |
| | They reported their practicum results in alignment with their actual activities. |
| Carefulness | Students followed the practicum steps correctly and accurately. |
| | They assembled the tools and materials for the practicum as instructed, without improvisation. |
| | Students conducted the practicum precisely and attentively. |

The findings above indicate that 1) Students demonstrate openness to exploration and a commitment to gaining a deeper understanding of the concepts being studied. 2) Students show growing discipline and an increasing awareness of the importance of adhering to scientific procedures. 3) The accuracy with which students conduct experiments and assemble them correctly reflects their strong integrity, even when learning independently without direct teacher supervision. These findings align with previous research, which suggests that laboratory-based learning fosters not only professional competence but also cultivates a culture of tolerance, collaboration, respect for differing opinions, and an appreciation of social diversity. Through laboratory activities, students develop positive, creative, and critical attitudes, enabling them to achieve scientific results while adhering to established scientific attitudes (4).

The reflective process of analyzing observations and deciding on actions within real-world contexts of virtual laboratories fosters critical thinking. This skill is intrinsically tied to the intellectual pursuit of understanding complex topics, driven by a desire to engage deeply with challenging concepts. Such engagement often leads to a heightened sense of intellectual satisfaction and mastery. Real-time educational simulations serve as viable alternatives to real-life experiences by closely replicating real-world scenarios and offering learning opportunities situated within authentic tasks (17). Educators have long recognized the interplay between learner attitudes and responses, noting a positive correlation between the two. As supported by previous research, “attitudes are evaluated beliefs that predispose individuals to respond in a preferential way.” This interconnectedness of attitudes and responses is similarly observed in virtual laboratory activities (18).

Additionally, to examine the interconnectedness and impact between the emergence of scientific attitude aspects and the conditions of asynchronous practicums—conducted with only worksheets and without teacher supervision—an axial coding process diagram was organized, as illustrated below.

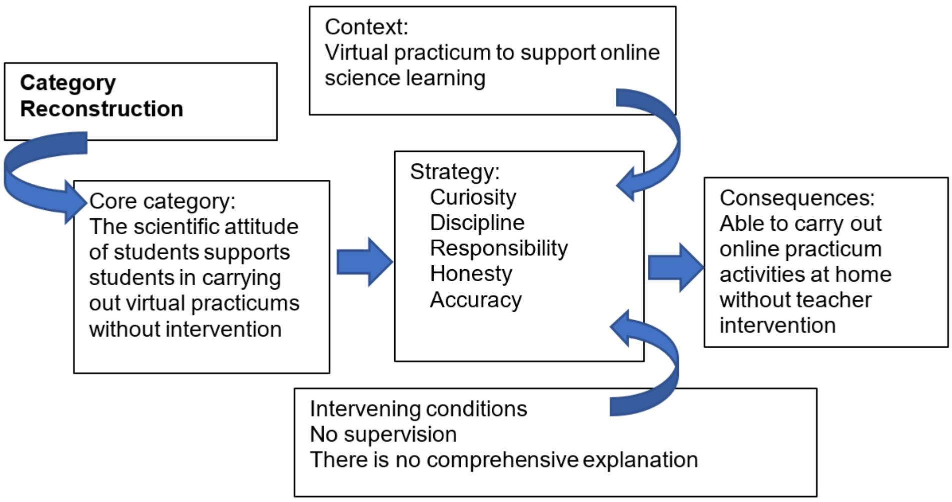


**Figure** 1: Axial Coding Process Diagram.

From the diagram above, we can conclude that students participating in online practicum activities using interactive PhET simulations demonstrated the ability to work effectively, as evidenced by behaviors reflecting a good scientific attitude during the coding process. This is shown through many behaviors that fit the category of scientific attitude in the coding process. However, the lack of direct teacher supervision can diminish student discipline, as reflected in incomplete submissions and reduced focus during some practicum activities. Despite these challenges, questionnaires and practicum recordings reveal that, for some students, the module serves as a valuable reference, supporting them in conducting virtual practicums effectively at home.

Practical activities in virtual laboratories have been shown to boost student motivation and offer opportunities for independent, self-paced learning. This is further supported by the ability of virtual laboratories to make students feel more engaged and enjoy practical activities significantly more than traditional hands-on experiments (19). Nevertheless, the effectiveness and efficiency of the learning process ultimately depend on students' active willingness and enthusiasm to participate (20). Therefore, as a recommendation, providing detailed worksheets and information about learning resources to support the understanding of practicum results would greatly enhance the effectiveness of asynchronous practicum sessions. Another recommendation is to conduct a pre-experiment session in the classroom, serving as a brainstorming activity to help students understand the clear objective that requires strategic planning and effective implementation of the planned actions (17), and post-experiment session to consolidate students' experiences with the virtual lab into a meaningful learning conclusion that can be understood by all students (15).

## 4. CONCLUSION

Based on the research findings, it was revealed that practical activities using virtual laboratories can effectively support the development of students' scientific attitudes, especially when supplemented with pre-lab activities to guide the experiments and post-lab activities to collaboratively draw meaningful conclusions from the completed practical work. The second finding indicates that the use of virtual laboratories particularly fosters scientific attitudes such as curiosity, critical thinking, and honesty. However, other aspects, such as responsibility and accuracy in conducting experiments, still require further training. Lastly, based on axial coding analysis, asynchronous virtual labs need to be accompanied by worksheets with detailed instructions and clear guidance on where to access the necessary learning resources to complete the experiments

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