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An Online Physics Laboratory Delivered Through Live Broadcasting Media: A COVID-19 Teaching Experience

Bayu Setiaji[1] and Purwoko Haryadi Santoso[2,3]

[1] Department of Physics Education, Universitas Negeri Yogyakarta, Indonesia; [2] Graduate School of Educational Research and Evaluation, Universitas Negeri Yogyakarta, Indonesia; [3] Department of Physics Education, Universitas Sulawesi Barat, Indonesia

Abstract

The COVID-19 pandemic has constituted a sudden educational transformation around the world. It has disrupted instructors, including physics educators, forcing them to adjust to remote teaching. The hands-on laboratory, one of the components of physics instruction, has also had to rapidly go online in all branches of this science, including nuclear physics. In this study, live broadcasting media was designed to conduct a remote nuclear physics laboratory. We then evaluated the immediate impact of this new mode of lab instruction on students' learning and attitude toward this type of instruction. Fifty-nine 3rd-year physics students at a public university in Indonesia participated in this study. The effectiveness of instruction was examined by analyzing both weekly reports and open-ended responses about students' learning experiences. In summary, it was evident that live broadcasting media was an effective way to conduct an online nuclear physics laboratory. Accordingly, students' attitudes demonstrated constructive behaviors about their remote laboratorial experiences. Our findings imply that online platforms are one way to offer the physics laboratory during unanticipated transitions such as the COVID-19 pandemic. Students' preference for a hands-on laboratory and the technical issues reported during the broadcasting session should be further examined to help design a remote nuclear physics laboratory that is even more accessible and enjoyable.

Keywords: online laboratory, nuclear physics, live broadcasting media, COVID-19

Introduction

The COVID-19 pandemic has been widely affecting educational practice since lockdown restricts direct interaction between teachers and students. Suddenly, educators worldwide have had to redesign their courses in order to offer remote instruction. Billions of students, teachers, and educational administrators are encountering turbulent situations as they sought to adapt to online learning formats to ensure educational sustainability.

Within the context of physics education, including nuclear physics course, COVID-19 has restricted laboratory activities which are compulsory for many undergraduate physics students. Broadly speaking, laboratory work is a key instructional element in promoting scientific practices that help explain conceptual physics in almost all physics domains. Earlier evidence has documented the potential of lab instruction for physics education (La Braca & Kalman, 2021; Moosvi et al., 2019; Ortiz, 2021; Phillips et al., 2021; Smith & Holmes, 2020; Zwickl et al., 2015). Due to the pandemic, unfortunately, laboratory instruction must be adjusted.

Such disruption can influence the effectiveness of physics labs. Reporting on the effectiveness of physics instruction is broadly acknowledged as the main intention of physics education research (PER; Docktor & Mestre, 2014; Odden et al., 2020; Santoso et al., 2022). In this study, students' performance and their attitude to the disruption were proxies to evaluate the effectiveness of online nuclear physics laboratories during the pandemic. Since the initiation of PER studies, learning transformation has been evaluated most often by probing student performance (Ding et al., 2006; Hake, 1998; Hestenes & Wells, 1992; Hestenes et al., 1992; Maloney et al., 2001). As well as the cognitive aspects, PER scholars are interested in examining the attitudinal variable that could be considered a supportive factor influencing effective instruction (Buxner et al., 2018; Crouch et al., 2018; Douglas et al., 2014; Fox et al., 2021; Kortemeyer, 2007; Mason & Singh, 2010; Werth et al., 2022).

The impact of the pandemic on postsecondary physics courses is particularly worthy of study. Recently, the disruption to education has been investigated, but these studies are focused on different sciences at the high school level (Abdullah et al., 2021; Juanda et al., 2021; Kartimi et al., 2021). Studies at the level of higher education are scant. To fill this gap, we decided that evaluating an online nuclear physics laboratory during the COVID-19 pandemic should be carried out.

A study by Rosen and Kelly (2020), undertaken before the pandemic, categorized online physics laboratories into several varieties. In this study, we selected *live broadcasting media* as the variety we wanted to examine. We evaluated students' learning processes and the impact of this transition on students' performance throughout the semester, and explored their attitudes towards using live broadcasting media to study nuclear physics. We posed two research questions:

1. How did students perform during the online nuclear physics laboratory throughout the semester?

2. What were students' attitudes about the remote nuclear physics laboratory during COVID-19?

COVID-19 has affected many aspects of educational practice. Supporting teachers by communicating PER findings and contributing progressive knowledge should be valuable in the long term. Experiences reported in this paper provide additional insights for physics educators wishing to evaluate learning processes during unanticipated crises such as a pandemic.

Methodology

Course Context

Universitas Negeri Yogyakarta (UNY) is one of the largest centres of Indonesian teachers' educators and educational researchers. Even though it is established in the Javanese region (home to the greatest Indonesian population), UNY's students come from not only the Javanese district but also from around the Indonesian archipelago. The admissions office registers almost 10,000 students every year, and they are distributed among heterogenous majors ranging from educational science, natural science, vocational, social sciences, and the humanities. The Faculty of Mathematics and Natural Science (FMIPA) of UNY organizes undergraduate and graduate programs. Within it, the Department of Physics Education prepares prospective Indonesian physics educators. Nuclear Physics (FIS 6117) is an experimental physics course taught to third-year students of modern physics. This field is populated mostly by experimental physicists. Thus, students must engage in laboratory work to dive into not only the content but also the epistemology of the field. Therefore, laboratory work is a key element of this course.

The nuclear physics laboratory at UNY is administered using an approach called *Learning Assistance*, which was developed at the University of Colorado (Otero et al., 2010). There are laboratory assistants recruited from among experienced students (enrolled in a higher year than the students they are assisting). They qualify for these positions by meeting certain requirements, thus ensuring their ability to handle nuclear physics experiments. Once a week, groups of students and assistants usually meet outside the classroom to discuss the experiments that are part of the course.

The nuclear physics course is taught during the first term of the third year. It starts in September and ends in December. During the 2020 lockdown, the nuclear physics laboratory had to adjust rapidly. The classic physics laboratory at UNY could no longer be administered, and it was instead offered remotely. This required the lab instructor to redesign the physics laboratory. Fortunately, a previous study by Setiaji & Dinata (2020) investigated the readiness of physics students at UNY to follow remote learning formats. Their readiness was measured by three proxies: (a) operating digital technologies, (b) understanding the e-learning system, and (c) interacting with online tools. Therefore, it was already evident that UNY students were prepared to be immersed in online routines.

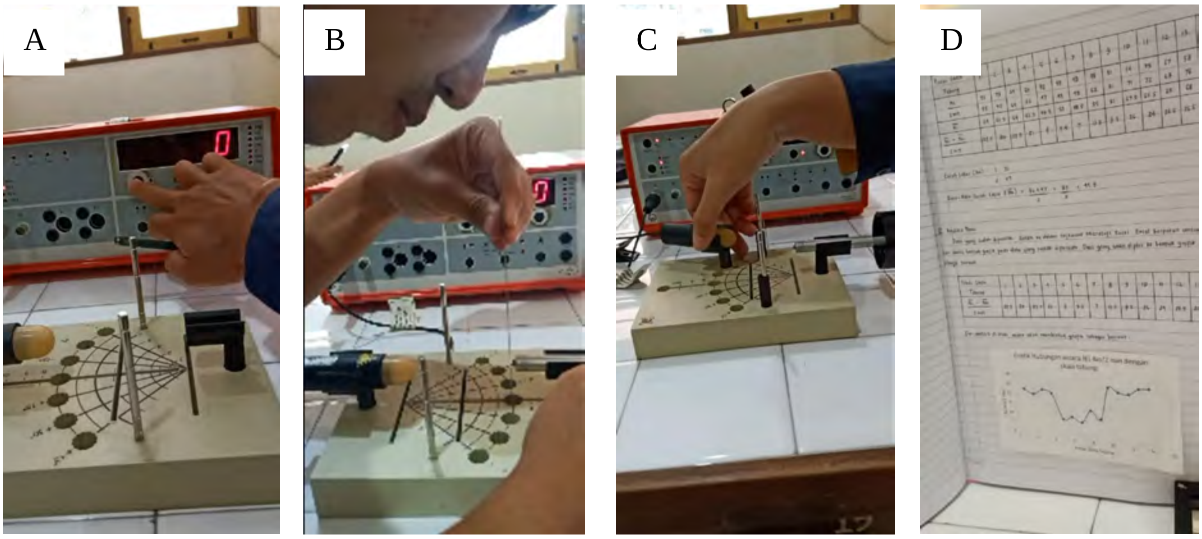
Study Design

This study is exploratory in nature. During COVID-19, the nuclear physics laboratory was designed to be delivered via live broadcasting media on the platform Instagram. Instagram has a live broadcasting channel. As evidenced by its number of users, Instagram is widely accessible and enjoyable for many users, which should include nuclear physics students, laboratory assistants, and lecturers.

This lab was designed to include two sessions, each delivered once a week. Students in each session were divided into three groups (6–7 students each, n = 59 students). Each week, one experiment was presented by the laboratory assistant (see Figure 1). Collaboratively, students carried out the experiment through a worksheet (in PDF format) developed for this online lab.

Figure 1

Live Online Nuclear Physics Laboratory Delivered by Laboratory Assistants



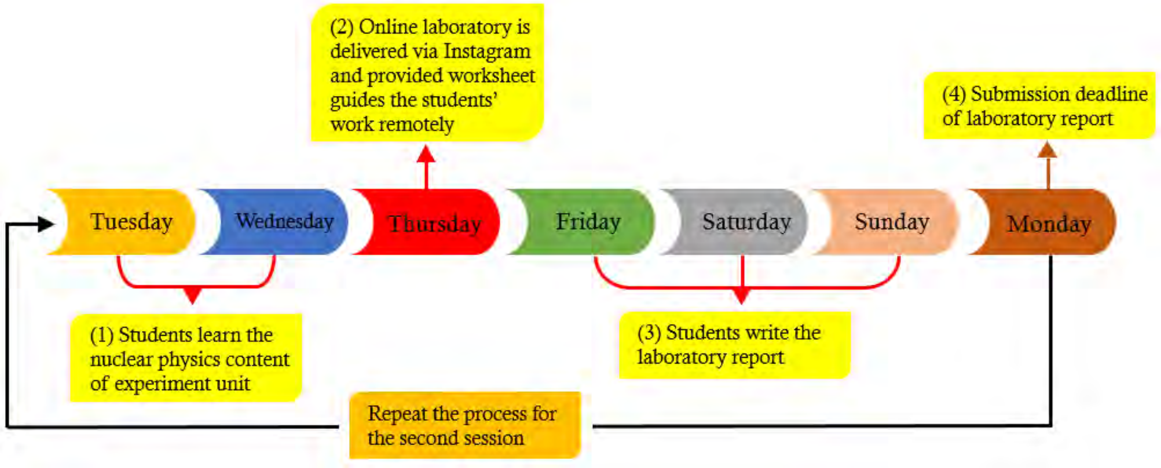
Note. Sample of students' activity through the Instagram Live channel. Panel A: Setting up the counter. Panel B: Preparing the Geiger-Müller detector. Panel C: Varying the mounting of the detector. Panel D: Explaining the format of the weekly laboratory report.

Prior to carrying out the live experiment, students studied material that was developed to provide initial information on a specific topic. This material was designed to help students "warm up" and be able to deal with problems arising from the topic. Providing this initial material ensured they had the ability to understand the lab activity, solve problems, and thus participate more effectively and efficiently.

Before the laboratory work commenced, students were offered, through video conference, introductory sessions during the first two weeks of the lecture. In the first week, the video conference introduced the course syllabus, experimental unit, and the grading rules. In the subsequent week, the lecturer presented the nuclear physics lecture on the topic of the upcoming laboratory work. After that, the weekly activities began (see Figure 2).

Figure 2

Weekly Activity of the Online Nuclear Physics Laboratory



First, students were assigned a worksheet with tasks to be carried out independently. We set up the students to be ready for the upcoming live session. Second, students were invited to the live session to observe the experiment presented by the laboratory assistants. Instead of merely observing the results, students were required to also remotely manipulate as many as five repeated measurements operated by the assistants. Third, a laboratory report of the recent experiment was to be written by students. Students were permitted to meet with their assistants through either the video conference or using the group chat function of the social media application WhatsApp. Difficulties that emerged either during the laboratory work or when writing the report would be addressed by the assistants. The laboratory report was to be submitted by students on the first day of the next week.

Simultaneously, the instructor prepared for the next lecture and graded the submitted reports based on a provided rubric (the rubric is described in the next section). These processes were repeated for the second laboratory session on the same experimental unit, and after two weeks, a new topic was introduced.

This online nuclear physics laboratory was divided into six units per session. Topics of the weekly experiment encompassed the introductory content of the undergraduate nuclear physics course as follows:

- Unit 1: Statistical property of nuclear radiation
- Unit 2: Attenuation coefficient and half-thickness
- Unit 3: Inverse-square law
- Unit 4: Radiation of lantern mantle
- Unit 5: Deflection of beta radiation in the magnetic field
- Unit 6: Radiographic method of filling level monitoring with gamma-ray

The whole remote laboratory activity ended after 16 weeks, which included 2 weeks for the lab introduction, 12 meetings for all live sessions, and 2 weeks for the final examination. The final test was designed to encompass the principle of performance assessment of the laboratory activity. It would be a proxy of the students' performance in this study and will be described in more detail in the next section.

Data Collection and Analysis

Students' performance in this study was measured through a weekly laboratory report and a final test at the end of the semester. Each student submitted one report, graded by the lecturer (the first author), on a weekly basis. In this work, we employed an adapted version of Rutgers' scientific abilities rubric (Etkina et al., 2006; Faletič & Planinšič, 2020) to assess students' laboratory reports. We looked at six aspects, standard to many laboratory reports: (a) clear purpose of experiment, (b) accurate data collection, (c) correct data analysis, (d) robust discussion, (e) solid conclusion, and (f) a complete reference used. After the weekly report had been graded, it was given back to students with attached feedback for their upcoming experiments. Finally, three open-ended items were administered during the final test (~90 minutes). These items were administered to assess students' scientific knowledge and to examine students' performance on data collection, data analysis, discussion, and drawing a solid conclusion. Validity of the final test was evaluated by PER experts with more than ten years' research and teaching experience with nuclear physics courses.

To answer research question 2, an additional set of open-ended items was included as a fourth item during the final examination. Within this item, three sub items were designed to probe student attitudes towards working with an online nuclear physics laboratory. Those aspects surveyed student feedback, experiences, and opinions regarding the effectiveness of their online physics laboratory during the COVID-19 pandemic. Students were encouraged to express themselves honestly and were told they could share their experience without any risk that their comments would be leveraged against their final course grade.

To answer research question 1, students' weekly reports and final exams were scored as a measure of student performance. Each student's data refers to six weekly reports and one final test. Their final course grade was calculated based on a weighted average of these two aspects. As determined by class consensus, weekly reports and final tests contributed 70% and 30% of the final grade respectively. Then, summary statistics were performed based on UNY academic rules. Numerical grades on the 100-point scale were converted to 4-point scaling grades and classified into qualitative predicates summarized in Table 1.

Table 1

Grading Scale of UNY Academic Rules

Interval	Letter grade conversion	
	Point value	Predicate
86 – 100	A	Very satisfying
81 – 85	A-	Satisfying
76 – 80	B+	Very good
71 – 75	B	Good
66 – 70	B-	Not good
61 – 65	C+	Very enough
56 – 60	C	Enough
41 – 55	D	Not enough
0	E	Bad

Then, to test the statistical significance of the effectiveness of our online nuclear physics laboratory, we used nonparametric statistics since, based on the Kolmogorov-Smirnov normality test, our data was not Gaussian distributed ($p > 0.05$; Kraska-Miller, 2013). We then implemented the one-sample Wilcoxon signed rank test (Corder & Foreman, 2014). It is a nonparametric alternative to the one-sample *t*-test when the data cannot be assumed as Gaussian distributed. It was used to determine whether the median of our sample was equal to a minimum passing grade of 56 based on UNY academic rules (Table 1).

To answer research question 2, we analyzed responses to the three open ended items during the final examination. Students' responses were qualitatively analyzed by two authors (B. S. and P. H. S.) and categorized based on nuance in the students' expressions. Conventional thematic analysis was employed to extract the essence of the textual data (Braun & Clarke, 2006; Nowell et al., 2017; Vaismoradi et al., 2016). After following the iterative processes of qualitative data analysis using RQDA packages within the R software environment (http://rqda.r-forge.r-project.org/; Huang, 2016), the same nuanced opinion was coded as the same categorization. Three categories of student attitude were saturated to report the essence of students' experiences in the online physics laboratory. There were three categories of student feedback (positive, negative, and neutral), student experience (Internet data plan, network quality, and no issues), and student opinion (hands-on lab, poor video quality, and still effective). To summarize the results, the number of students representing each of the categories within a sample were counted and visualized as a pie chart (see Figure 5).

Results and Discussion

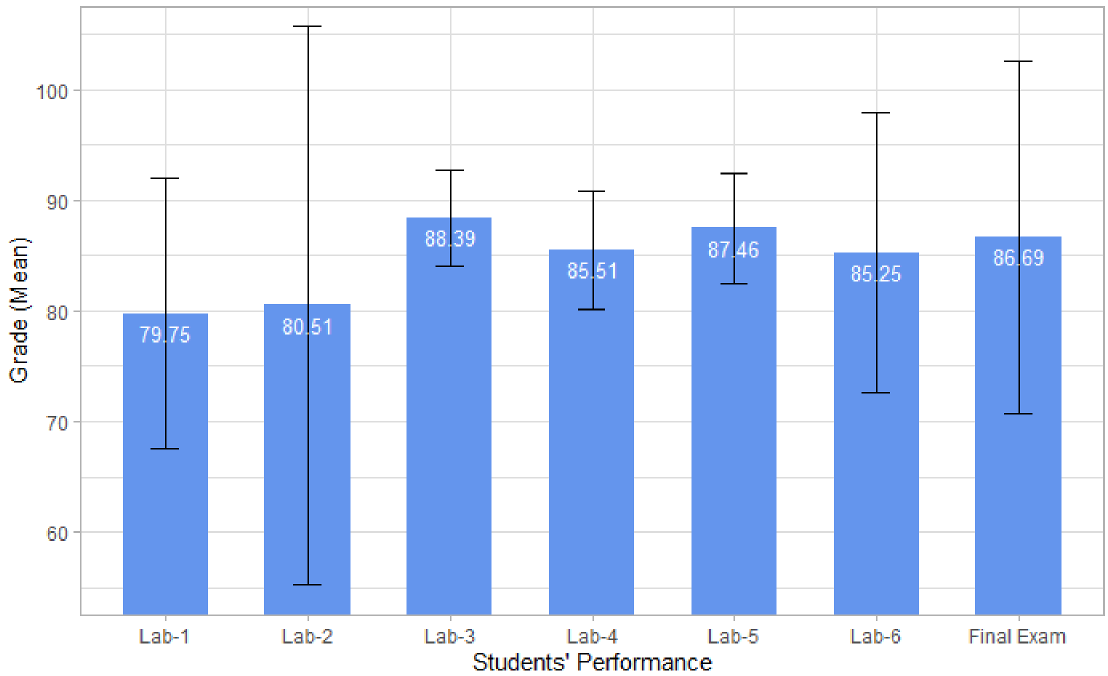
Students' Performances in the Online Nuclear Physics Laboratory (Research Question 1)

Students' performance was initially measured based on the weekly laboratory reports. In each laboratory unit, students had to submit a weekly report of the most recent experiment. This assignment was assumed to be a controlling system of students' attendance. Previous research has demonstrated that this treatment can maintain students' motivation in an online environment (Eckert et al., 2009). We expected that all students would maintain their intentions throughout the learning process.

The class mean of student performance in terms of weekly laboratory reports and final examination throughout the semester is summarized in Figure 3. In general, most students obtained the *very good* predicate as defined in Table 1 on each of the weekly laboratory reports and final exam. Students reached *very satisfying* performance (> 86) in the third and fifth laboratory reports. Unfortunately, the first two experimental units underperform to the subsequent laboratorial activity. This could be explained since the starting experiments required students to plot the decay distribution of the frequency background occurring within 10 seconds for 100 times using a Geiger-Müller detector. Admittedly, students must be able to make sense of the decay distribution on this task. Most students, however, still have limited experience in plotting and interpreting such graphs due to this being their first time in this nuclear laboratory. Even though they should have employed some graphical tasks in their previous learning path—recent reports state that graphical representation is imperative for physics learning (Hidayatulloh et al., 2021; Nixon et al., 2016; Skrabankova et al., 2020)—in fact students still need further training in this area. Accordingly, we tailored a tutorial after the second laboratory unit to help with plotting and interpreting visualizations to improve students' representational ability in nuclear physics.

Figure 3

Mean of Weekly Reports and Final Examination Grade (n = 59*).*



Note. Horizontal axes represent assessment points during the semester. There were six weekly laboratory reports and one final examination.

The third experiment was designed to study the inverse square law based on radium (Ra) radiation (226.33 becquerels). After conducting the experiment, students needed to examine the interplay between the distance of the radiation source in a thin-walled, cylindrical end-window tube and the decay rate of the radioactive source. After the tutorial, students should be able to achieve better performance based on a significantly improved average grade on this third experiment ($p < 0.05$).

The fourth experiment aimed to allow students to study the radiation decay of a lantern mantle containing 1.3 grams of thorium as a radioactive source. In this experiment, students were still provided with training in graphical representation. However, the average grade decreased non-significantly ($p > 0.05$). During this time, we experienced network problems that distracted students taking part in the live laboratory meeting. To overcome this problem, we uploaded a recorded file of the session, allowing students to access it on other occasions accordingly.

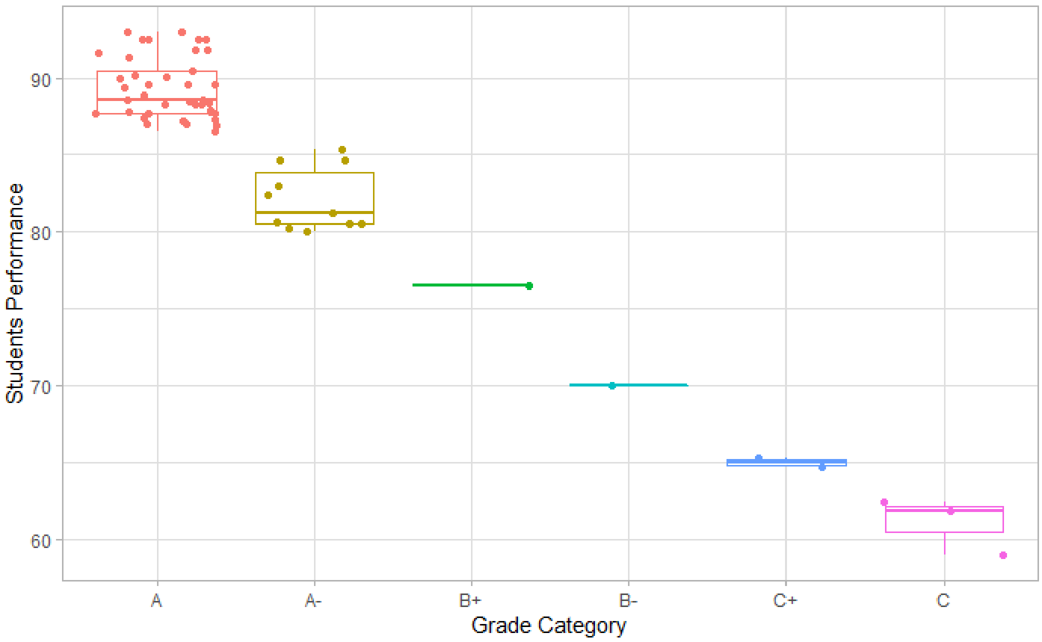
The fifth experiment was designed to observe the deflection of beta radiation within the magnetic field. The beta-ray was produced by Ra-226 radiation in this experiment. As shown in Figure 3, the average student performance increased from the fourth meeting non-significantly ($p > 0.05$). This average was categorized as *very satisfying*, as defined in Table 1. Eventually, students ended their laboratory sessions with a radiographic method of filling level monitoring (FLM) with gamma-rays. This experiment aimed to calculate the filling level using a radiation gate (between the radiation source and a thin-walled, cylindrical end-window tube). This experiment was performed by putting lead powder into a plastic tube. The decrease of students' average grades occurred non-significantly ($p > 0.05$).

In addition to the weekly report assessment, student performance was also probed using a final examination that contributed 30% to the final grade of nuclear physics course (FIS 6117). The final examination aimed to measure students' ability using the Rutgers' scientific abilities rubric (Etkina et al., 2006; Faletič & Planinšič, 2020). Three open-ended items examined students knowledge about their experimental data from the former labs. The mean of the final test was 86 or equal to the *very satisfying* predicate as defined in Table 1.

Eventually, the final grade was calculated using the weekly grades and the final exam. Based on the UNY academic rules (Table 1), the minimum passing grade for our nuclear physics course must be 56 (*C* predicate). Figure 4 summarizes how the students' performances (final course grade) were distributed within our sample.

Figure 4

Distribution of Students' Performance Based on Final Grade



Most students (more than half) were within the *A* predicate, outperforming other groups of predicates. Moreover, only one student obtained each a *B*+ and *B*– predicate, thus there is no standard deviation (or box) representing these grade categories in Figure 4. The number of *C*+ and *C* students was larger than the *B*+ and *B*– predicates.

Inferential statistics were then employed to test the effectiveness of the online nuclear physics laboratory based on the student performance to achieve the minimum passing grade (56). The one-sample Wilcoxon signed rank test was performed to test the difference between the median data and the median test (the minimum passing grade = 56). We discovered a significant difference between median data and the minimum passing grade ($p < 0.05$). This statistical evidence suggests that live broadcasting media can be used with students learning nuclear physics during the unanticipated outbreaks. It can be an alternative way to adapt the physics laboratory to prevailing conditions during times of change such as the COVID-19 pandemic. This supports earlier research that found online media must be effective and efficient to support remote-based learning (Al-Said, 2015).

These findings imply that using live broadcasting media to deliver an online nuclear laboratory could continue beyond the COVID-19 pandemic. This would help students conduct real experiments indirectly and subsequently engage with concepts of nuclear physics during laboratory work. This is in line with an earlier study reported by Moosvi et al. (2019) that argued that online laboratory activity could remain as an alternate form of the physics laboratory in future.

Students' Attitudes About the Remote Nuclear Physics Laboratory During COVID-19 (Research Question 2)

Students' attitudes were measured using three open-ended items. Figure 5(a) shows the results of the first open-ended item which concerned student feedback. Positive feedback dominated the result (58%).

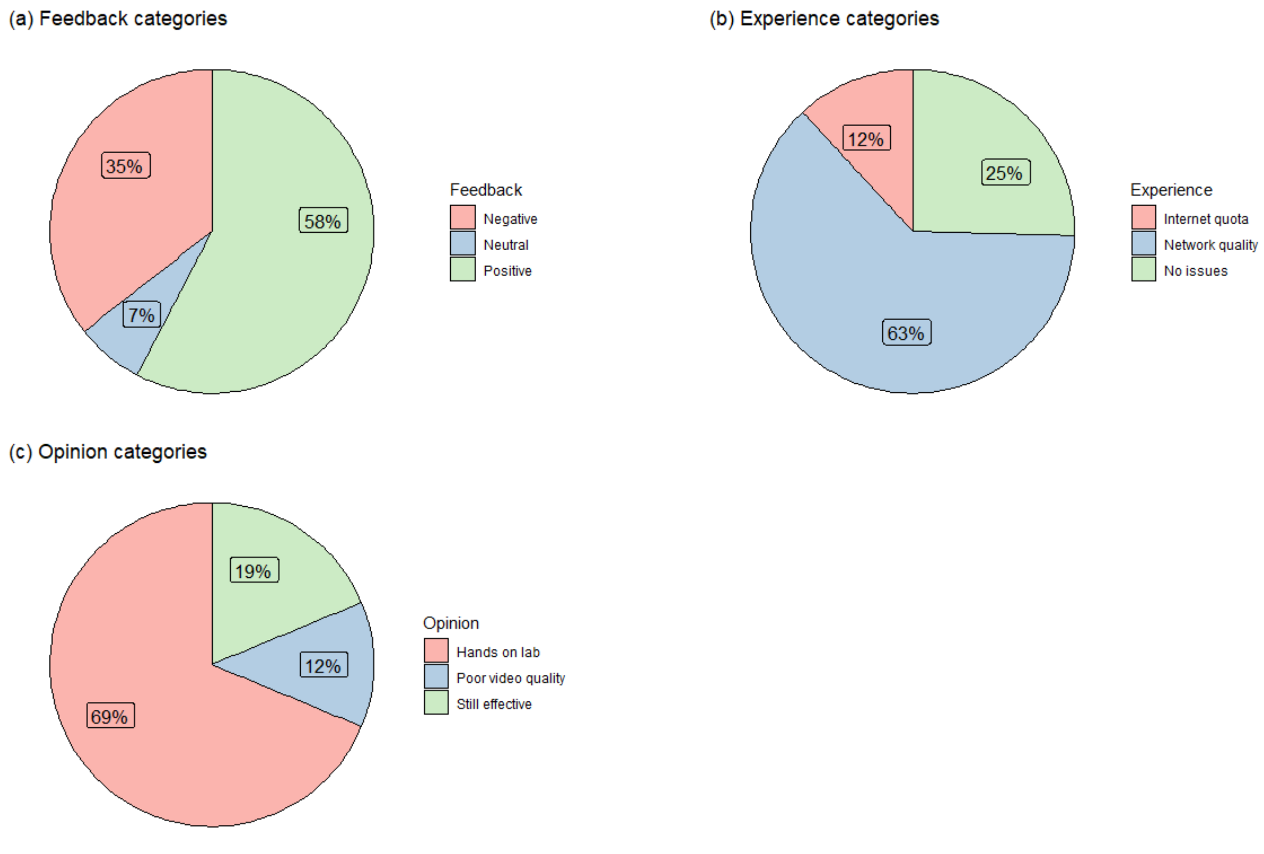
Most students expressed appreciation to the lecturers, laboratory assistants, and administrators for the roles they played facilitating the real experiments during the COVID-19 pandemic. One example of positive student feedback came from Joko:

> Thank you in advance for providing a live session of the laboratory. In general, these online laboratory activities are very helpful for students in solving experimental physics problems during the pandemic. It is valuable to our understanding because we are immersed in the real experiments. The laboratory assistants responsively help us to explain it and even assist us with the analytical calculations.

On the other hand, Figure 5(a) reveals that 35% expressed negative feedback. This should not be ignored. It can be driven since some students encountered technical issues during the live session, i.e., poor network quality. In addition, some students expressed criticism related to the camera angle. These criticisms and suggestions will be discussed in more detail in the section covering students' opinions.

Figure 5

Distribution of Student Feedback, Experience, and Opinion



Note. n = 59.

Students were also surveyed to describe their experiences with the online physics laboratory. Students' experiences are shown in Figure 5(b). Most of the experiences reported were clustered as network quality issues in their homes (63%). There were also a significant number (12%) who expressed frustration with the limited internet data plan. However, about a quarter of our sample reported no significant issues during the live sessions. On the one hand, network quality and data plan availability were still the main concerns of students. As expressed by Kinan, "Signal problems, both from my device and from the live streamer. They sometimes transmit the poor video quality. My internet data plan is limited to follow the live session for hours."

Undoubtedly, network issues are a fundamental problem for most Indonesian students. Online learning obstacles are due not only to the unaffordable Internet data plan but also to gaps in network infrastructure, particularly in remote areas of Indonesia (Rayuwati, 2020). In fact, UNY had provided assistance of the mobile data plan to our students with their online learning. Moreover, the Indonesian Ministry of Education, Culture, and Higher Education had a policy to support this intention particularly students and lecturers with their Internet data plan (15 GB for a month) during the timeframe of the COVID-19 pandemic.

In the third open-ended question, students were asked for their opinions about the effectiveness of using live broadcasting media to conduct a nuclear physics laboratory. As shown in Figure 5(c), 19% of students believed that an online laboratory delivered through live broadcasting media could be effective. During the COVID-19 pandemic when all students were required to learn from home, using live broadcasting media to conduct experiments enabled students to proceed with their education. However, most students argued that hands-on experiments would be more preferable for experimental physics. They suggested that direct interaction with real apparatus would be better, allowing them to gain more experience with real physics phenomena. Stark (2019) has reported that students' motivation can be greater in a hands-on physics laboratory.

Additionally, the most dominant opinion concerned video quality. Assistants and lecturers who managed the video capture at that time focused primarily on delivering the nuclear physics laboratory. Focusing on the apparatus rather than the shooting angle was meant to facilitate understanding of how the apparatus should be set up. Thus, it was believed, students would understand the technical part of the physics laboratory more clearly. In future, we should pay greater attention to the angle of the camera in the video.

The biggest problem for students as shown in Figure 5(b) was the network. Tumirah recommended:

> To overcome my slower network problem, I move to a place around my house that performs better signals. If it is still a bad connection, I will find help from my family member whose SIM card signal is good to provide network tethering for my device.

We took these issues into consideration when we later provided a recorded file of the live sessions to students. This facilitated students who were limited by network issues during the live laboratory session to proceed with their coursework.

Moreover, we created a discussion room on Instagram where students could give comments or post questions or feedback. We also created a WhatsApp group for assistants and students outside the live broadcasting session. This communication channel was designed for students who encountered difficulties during the synchronous activity. Live broadcasting media still requires further improvements to make students' experiences more accessible and enjoyable. Some of the criticisms and suggestions can guide further enhancement of the online form of physics experiments.

One of the advantages of using live broadcasting media for physics laboratories is the sustained interaction during laboratory work. Students can discuss the experiments with lecturers and lab assistants who provide comments or feedback. Interaction is a key element of the successful implementation of remote based learning (Al-Said, 2015; Lu et al., 2018; Rodriguez-Gil et al., 2018). In addition, students who experience network limitations can access the recorded version of the live session. Another benefit is the opportunity for student engagement. They are immersed in laboratory work delivered by laboratory assistants in real time. Hence, students may gain more experience with the actual apparatus than if they were involved in virtual simulation (Finkelstein et al., 2005). As an impact, students will have a better conceptual understanding about nuclear physics.

Our findings on student performance and attitude about learning experiences are supported in several recent studies (Fox et al., 2021; Marzoli et al., 2021). These articulated that online tools such as live broadcasting media, video conference, or the virtual laboratory were options for all physics instructors who wished to maintain the laboratory class during COVID-19. Various learning platforms have been used as communication tools in physics teaching recently, such as Zoom (O'Brien, 2021), PhET (Wieman et al., 2008), Labsland (Orduña et al., 2016), and Olabs (Ortiz, 2021). Students' have demonstrated positive attitudes regarding an online nuclear physics laboratory delivered using live broadcasting media. Though the pandemic was an emergency, students did not give up in studying physics.

On the other hand, physics students still experienced learning obstacles in the context of graphical representation. In fact, this ability is imperative for physics conceptual understanding and problem solving (Docktor & Mestre, 2014; Hidayatulloh et al., 2021; Odden et al., 2020; Santoso et al., 2022). To address this issue, instructors should empower students to acquire this skill, using teaching tools such as scaffolding (Rangkuti & Karam, 2022), contextual tasks (Scheid et al., 2019), and obviously, as we discovered in our third meeting, tutorials (Kohnle & Passante, 2017).

Moreover, Lischer et al. (2021) and Patricia Aguilera-Hermida (2020) discovered another case of using online education during the COVID-19 pandemic. They reported the potential psychological effects encountered by students toward online teaching. In this study, students' opinion (Figure 5(c)) discovered that most of them prefer to acquire the hands-on lab rather than live broadcasting media. In addition, the number of students who experienced network problems during the live session (Figure 5(b)) cannot be avoided from our attention to evaluate our teaching throughout the circumstance. Those effects can correlate with the few students in expressing their negative attitudes in Figure 5(a) toward the online physics laboratory. Even the issue of psychological effects is not intended in our study, future scholars can examine this hypothesis that can contribute to the deeper investigation of the student attitude toward the learning process during the COVID-19 pandemic.

The current study has several limitations that could be addressed within future research. For one, the research design may be questioned. Moreover, the nonparametric statistics employed in this study uses merely the passing grade value as the statistical measure. For greater generalizability, future attempts should acknowledge a more solid experimental design and statistical method to compare different modes of online physics laboratory. In addition, further research is needed to evaluate whether our work could be a best practice in other STEM disciplines. As a final remark, an online physics laboratory offered through live broadcasting media cannot replace a hands-on physics laboratory as indicated in students' responses. The online laboratory reported in this paper was a shared experience of learning adaptation during the challenge of the COVID-19 pandemic. Obviously, further research is warranted to investigate specific impacts of these strategies and their relationships with the remote learning experience in physics.

Conclusion and Recommendation

In this study, live broadcasting media was designed for an online nuclear physics laboratory. This form of course delivery was effective since all students reached the minimum passing grade. Live broadcasting media should be considered as an alternative channel to administer a physics laboratory online during pandemic restrictions. Still, learning graphical representation skills within an online nuclear physics laboratory poses problems for some students. However, students improved in this area after receiving intervention in the form of tutorials created by the authors.

Most students expressed positive attitudes regarding the online laboratory and stated that the live broadcasting media was engaging and effective. On the other hand, poor network quality, limited Internet data plan, and insufficient quality of video transmission were drawbacks reported in our study. Therefore, enhancements to address these problems should be thoughtfully developed. For any further investigation into this area, the live broadcasting media could be compared either with other online media, with offline nuclear laboratory activities, or with other STEM courses. Moreover, configuring the video to improve quality will make the laboratory activity more accessible and enjoyable. Using live broadcasting media for online nuclear laboratory activities can serve as a baseline to develop other online learning resources.

This research offers additional insight for educators. Even without face-to-face interaction, physics education can be effectively delivered, even in the case of the experimental physics laboratory. There remains a question of whether remote activity will remain a part of instruction in future once pandemic restrictions have been lifted. The answer presents a further challenge for future investigations.

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