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Effectiveness of the CCDSR model assisted by practical experiment videos in improving students' science process skills in quantum physics

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ABSTRACT

This study examined the effectiveness of the CCDSR model assisted by practicum videos in improving students' science process skills (SPS) in learning atomic spectra and energy quantization. A quasi-experimental one-group pretest-posttest design involved fifth-semester Physics Education students at Khairun University from two consecutive academic cohorts. Total sampling was applied, involving 27 students in 2023–2024 and 16 students in 2024–2025. Data were collected using pretest and posttest SPS instruments and analyzed using descriptive statistics, normalized gain (N-Gain), and paired-samples t-tests. The results showed substantial improvements in SPS across all classes. Mean scores increased from 8.9 to 70.9 in Class VA, 10.6 to 67.5 in Class VB, and 9.1 to 75.3 in Class VAB, with N-Gain values of 0.7, 0.6, and 0.7, respectively. These findings indicate that the CCDSR model assisted by practicum videos effectively improves students' SPS and supports the learning of abstract physics concepts, particularly atomic spectra and energy quantization.



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Introduction

Quantum Physics is widely regarded as a difficult course among students in the Physics Education Study Program, Faculty of Teacher Training and Education, Khairun University. The difficulty is particularly evident in topics such as atomic spectra and energy quantization, which involve abstract microscopic phenomena, mathematical representations, and relationships between theoretical models and observable physical evidence. These characteristics become more challenging when instruction is conducted online because students have limited opportunities to directly observe phenomena and engage in experimental activities. In conventional lectures dominated by discussion and presentation, students also tend to be passive, making it difficult for them to develop the skills required to interpret phenomena and connect mathematical representations with physical concepts. This condition was reflected in the 2022–2023 academic year, when 47.8% of fifth-semester students reported difficulties in understanding the material even after completing the learning process. Interviews with 10 students further indicated that atomic spectra and energy quantization were perceived as highly abstract and difficult to visualize. These problems are consistent with previous studies reporting that students experience difficulties in Quantum Physics because of the abstract nature of the concepts (Singh & Marshman, 2020), difficulties relating mathematical equations to physical phenomena such as the Schrödinger wave function and

Hilbert space (Kohnle & Passante, 2019), the high complexity of quantum topics (Johnston et al., 2021), and the limited effectiveness of traditional instructional approaches in developing meaningful understanding of quantum physics (Singh & Chandralekha, 2022).

The persistence of these difficulties indicates that the problem is not merely the complexity of quantum physics content but also the way students are guided to construct and verify their understanding. Conventional discussion-presentation approaches tend to emphasize the delivery of theoretical information and mathematical procedures, whereas atomic spectra and energy quantization require students to observe evidence, identify patterns, interpret data, formulate explanations, and relate empirical representations to abstract theoretical concepts. Consequently, students may be able to reproduce equations without necessarily understanding how those equations represent physical phenomena. This limitation is particularly important because quantum physics cannot be effectively learned only through conceptual explanation; students need opportunities to investigate phenomena and construct relationships between experimental evidence and theoretical representations. Thus, an instructional approach that systematically engages students in scientific investigation while providing concrete representations of abstract quantum phenomena is needed.

Previous studies have demonstrated the potential of active and inquiry-oriented approaches to address these challenges. Lin et al. (2025), for example, found that guided-inquiry-based quantum physics instruction improved students' understanding of discretized energy levels by up to 40% and helped students recognize the relationship between wavelength and energy through hydrogen-spectrum simulations. Similarly, Zhu and Singh (2012), McKagan et al. (2008), and Chen and Zhao (2019) developed learning activities that enabled students to interpret experimental data through projects involving atomic energy spectrum models, resulting in improved understanding of energy quantization and its application in LED technology. However, these studies primarily emphasize conceptual understanding, simulation, or project-based activities and do not specifically examine the effectiveness of a structured learning model that integrates the development of science process skills with practicum-based video support. Therefore, although previous research confirms the value of inquiry, simulation, and experimental representation in quantum physics learning, the pedagogical mechanism for systematically developing students' science process skills while learning abstract quantum concepts remains insufficiently explored.

Science Process Skills (SPS) are particularly relevant to this problem because learning atomic spectra and energy quantization requires students to perform processes that resemble scientific investigation. Students need to observe spectral patterns, classify or identify characteristics of observed phenomena, measure and interpret experimental data, identify relationships between wavelength and energy, formulate explanations based on evidence, and communicate conclusions. These activities correspond directly to the processes through which students move from observable evidence toward abstract quantum explanations. In quantum physics, the ability to interpret experimental data and construct conceptual models is essential for developing deeper conceptual understanding (Nieminen & Virtanen, 2020). Moreover, quantum science process skills enable students to apply quantum theory to real-world situations through problem-solving activities involving thought experiments and mathematical predictions (Styer & Christensen, 2022). Developing these skills also enables students to connect theoretical predictions with experimental results (Kohnle & Passante, 2019) and to evaluate theories and experimental findings objectively (Zollman & Rebello, 2022). Investigative activities are therefore particularly appropriate for quantum physics because understanding microscopic phenomena often requires students to explore relationships that cannot be directly observed (Bohr & Feynman, 2016).

More broadly, Science Process Skills encompass procedural, experimental, and systematic abilities that constitute an essential foundation of scientific knowledge (Alkan, 2016; Arabacioglu & Unver, 2015; Colvill & Pattie, 2002; Dogan & Kunt, 2016; Karsli & Ayas, 2014; Karsli & Şahin, 2009; Suyidno, Nur, Yuanita, & Prahani, 2017). These skills are important for students and prospective teachers because mastery of physics involves not only understanding scientific concepts but also engaging in the processes through which scientific knowledge is constructed (Limatahu, Suyatno, & Prahani, 2018; Prahani, Nur, Yuanita, & Limatahu, 2017; Yunita, Poedjiastoeti, & Agustini, 2017). SPS has also been identified as an important component in improving physics mastery (Limatahu et al., 2018; Rahman & Limatahu, 2020). The Science-A Process Approach (SAPA) distinguishes SPS into basic and integrated process skills, including observing, classifying, measuring, communicating, inferring, predicting, identifying relationships, interpreting data, formulating hypotheses, and designing investigations. In the context of atomic spectra and energy quantization, these skills are not merely general scientific abilities; they constitute the cognitive and procedural processes needed to transform experimental observations into an understanding of quantum concepts.

Despite the established importance of SPS, previous research has not sufficiently connected the development of these skills with the specific instructional challenges of atomic spectra and energy quantization. More importantly, the existing literature provides limited empirical evidence concerning whether students who

experience difficulties with these topics can improve their SPS through a learning model that systematically organizes scientific investigation and is supported by practicum videos. This represents an important research gap because video-supported practical activities may provide students with visual and procedural representations of experiments that are difficult to conduct directly, particularly when learning involves abstract phenomena or limited laboratory access. However, the effectiveness of such media depends on how they are pedagogically integrated into the learning process. Simply providing practical videos may not be sufficient if students remain passive viewers rather than active investigators.

The CCDSR model offers a potential pedagogical framework for addressing this limitation because it can organize learning around students' active engagement with scientific phenomena, conceptual construction, discussion, and reflection. When assisted by practicum videos, the model can provide students with observable experimental representations of phenomena that are otherwise difficult to visualize while simultaneously guiding them to perform the processes required to interpret those phenomena. The combination is theoretically relevant to atomic spectra and energy quantization because students can observe experimental representations, identify patterns, interpret evidence, connect observations with mathematical relationships, and construct explanations of quantum phenomena. Thus, the value of the CCDSR model in this study does not lie merely in replacing conventional instruction, but in providing a structured mechanism through which practicum videos become part of a scientific learning process aimed at developing SPS.

Accordingly, the novelty of this study lies in examining the effectiveness of the CCDSR model assisted by practicum videos specifically for improving students' Science Process Skills in learning atomic spectra and energy quantization. Unlike previous studies that have predominantly investigated conceptual understanding through guided inquiry, simulations, or project-based learning, this study positions SPS as the primary learning outcome and integrates practicum videos within the CCDSR learning process. This approach addresses both the abstract characteristics of quantum physics and the need for active scientific engagement. The study therefore seeks to provide empirical evidence regarding whether the integration of the CCDSR model and practicum videos can produce meaningful improvements in students' SPS and offer an alternative instructional strategy for teaching abstract quantum physics concepts.

Based on the identified learning problems, theoretical considerations, and research gap, this study aims to examine the effectiveness of the CCDSR model assisted by practicum videos in improving students' Science Process Skills in learning atomic spectra and energy quantization. The study is expected to contribute empirically to the development of quantum physics instruction by demonstrating how a structured learning model combined with visual-practical media can support students in connecting experimental evidence, scientific processes, and abstract quantum concepts.

Method

Research Design and Participants

This study employed a quasi-experimental approach using a one-group pretest-posttest design to examine the effectiveness of the CCDSR model assisted by practicum videos in improving students' Science Process Skills (SPS) in quantum physics learning. The one-group pretest-posttest design was selected because all participants received the same instructional treatment and were assessed before and after the intervention. No separate control group was involved in this study.

The research was conducted in the Physics Education Study Program, Faculty of Teacher Training and Education, Khairun University, during the 2023–2024 and 2024–2025 academic years. The participants were fifth-semester students enrolled in the Quantum Physics course. In the 2023–2024 academic year, the participants consisted of Class VA (16 students) and Class VB (11 students), while in the 2024–2025 academic year, the participants consisted of Class VAB (16 students). Thus, the total number of participants was 43 students. A total sampling technique was employed because the number of students in each class was relatively small and all students enrolled in the relevant course were accessible to the researcher.

The use of two consecutive academic cohorts was intended as a replication of the intervention rather than a comparison between academic cohorts. The same learning objectives, learning materials, instructional procedures, practicum activities, learning model, practicum videos, and assessment procedures were applied across the three classes. This replication was conducted to examine whether the observed improvement in SPS was consistent when the same intervention was implemented in different academic cohorts. To minimize potential differences between cohorts, the treatment was implemented using the same instructional scenario, learning materials, practicum procedures, assessment rubric, and researcher as the model lecturer.

Learning Intervention

The intervention was conducted over five face-to-face meetings, comprising three theoretical sessions and two practicum sessions focusing on hydrogen or neon gas spectra and energy quantization. To ensure consistency across the three classes, the researcher served as the lecturer and used identical lesson plans, learning materials, practicum videos, instructional sequences, assessment rubrics, and learning durations. An implementation checklist was also used to monitor adherence to the CCDSR procedure. During the learning process, students were introduced to relevant problems, activated their prior knowledge, and observed practicum videos as visual and procedural stimuli for understanding experimental phenomena that are difficult to visualize directly in Quantum Physics. Through the subsequent CCDSR activities, students collaboratively formulated problems and hypotheses, identified variables, designed experimental procedures, conducted investigations, collected and analyzed data, and interpreted experimental evidence, while the lecturer facilitated the process without directly providing the expected conclusions.

Following the practical activities, students related their experimental findings to the concepts of atomic spectra and energy quantization, reconstructed practicum videos based on their investigations, presented their findings, and participated in discussion and reflection. These activities were designed to strengthen students' scientific reasoning, communication, and ability to connect experimental evidence with abstract Quantum Physics concepts. Students' Science Process Skills (SPS) were assessed using a structured rubric adapted from the instrument reported in previous research [18]. The assessment covered nine SPS indicators: (1) formulating problems, (2) formulating hypotheses, (3) identifying variables, (4) defining operational variables, (5) designing experiments, (6) collecting data, (7) summarizing observations, (8) analyzing data, and (9) formulating conclusions.

Data Collection Procedure

Data collection was conducted through pretest, learning intervention, and posttest. The pretest was administered before the implementation of the CCDSR model assisted by practicum videos to establish students' initial SPS. The intervention was subsequently implemented during the five learning meetings. After the intervention was completed, students were administered the posttest using the same SPS assessment framework. The assessment focused on students' performance in carrying out scientific processes rather than merely recalling quantum physics concepts. Students' responses and performance were assessed using the predetermined SPS rubric. The same assessment criteria were applied across the three classes to ensure comparability of the results.

Data Analysis

The data were analyzed quantitatively to determine changes in students' SPS before and after the intervention. Descriptive statistics were used to summarize students' pretest and posttest scores, including the mean scores and improvement patterns for each class. The magnitude of improvement was determined using the normalized gain (N-Gain), calculated as:

$$g = (\text{Posttest} - \text{Pretest}) / (100 - \text{Pretest})$$

The N-Gain values were interpreted according to the commonly used categories of low ($g < 0.30$), moderate ($0.30 \leq g < 0.70$), and high ($g \geq 0.70$).

Because the same students were measured before and after the intervention, a paired-samples t-test was used to determine whether the difference between pretest and posttest SPS scores was statistically significant. This test was selected because the analysis involved two related measurements obtained from the same participants. The significance level was set at $\alpha = 0.05$. A p-value below 0.05 was interpreted as indicating a statistically significant difference between students' SPS before and after implementation of the CCDSR model assisted by practicum videos. Statistical analysis was performed using SPSS version 21.0.

Results and Discussions

The results of the study indicate that students' science process skills increased in N-Gain. This indicates an increase in students' potential understanding after participating in the learning process. The increase in science process skills across all classes studied is presented in Table 1 below.

Table 1. N-Gain of Students' Science Process Skills

Class	Pretest	Posttest	N-Gain
VA	8.9	70.9	0.7
VB	10.6	67.5	0.6
VAB	9.1	75.3	0.7

Based on Table 1, students' Science Process Skills (SPS) improved across all three classes following the implementation of the CCDSR model assisted by practicum videos. Mean scores increased from 8.9 to 70.9 in Class VA, from 10.6 to 67.5 in Class VB, and from 9.1 to 75.3 in Class VAB, with N-Gain values of 0.7, 0.6, and 0.7, respectively; according to the N-Gain classification [34], the improvements in VA and VAB were categorized as high, while VB was categorized as moderate. The paired-samples t-test further confirmed that the pretest-posttest improvement was statistically significant, supporting the effectiveness of the intervention beyond descriptive N-Gain results. Although differences among classes may reflect variations in initial conditions, engagement, participation, or learning dynamics, these factors were not directly examined and therefore cannot be considered causal explanations. Overall, combining practicum videos with active investigation through the CCDSR model may facilitate students' engagement in observing, collecting and interpreting experimental evidence, and connecting abstract quantum concepts with observable representations, thereby supporting SPS development.

The relatively lower N-Gain in Class VB does not indicate an absence of improvement. Rather, the moderate N-Gain demonstrates that the students still experienced a meaningful increase in SPS, although the magnitude was lower than that observed in Classes VA and VAB. This finding suggests that the implementation of the CCDSR model assisted by practicum videos can produce positive changes across different classes, while the magnitude of improvement may vary depending on contextual and learner-related conditions. Overall, the findings indicate that the intervention was associated with significant improvement in students' SPS, particularly in learning abstract quantum physics topics such as atomic spectra and energy quantization. Nevertheless, because the study employed a one-group pretest-posttest design without a control group, the findings should be interpreted as evidence of improvement following the intervention rather than definitive evidence that the intervention alone caused the observed changes. A summary of the average pretest and posttest scores, as well as the average N-Gain from lab activities I and II, is presented in Table 2 below.

Table 2. Mean pre-test, post-test, and N-Gain scores

Class	Practical	Pretest	Posttest	N-Gain
VA	I	7.8	69.8	0.7
VA	II	9.9	72.0	0.7
VA	Average	8.9	70.9	0.7
VB	I	9.8	66.2	0.6
VB	II	11.4	68.7	0.6
VB	Average	10.6	67.5	0.6
VAB	I	8.0	74.0	0.7
VAB	II	10.1	76.6	0.7
VAB	Average	9.1	75.3	0.7

Based on Table 2, students' initial Science Process Skills (SPS) varied across classes and practicum activities, with Class VB showing the highest overall mean pretest score (10.6), followed by VAB (9.1) and VA (8.9). Pretest scores were also consistently higher in Practicum II than in Practicum I, increasing from 7.8 to 9.9 in VA, 9.8 to 11.4 in VB, and 8.0 to 10.1 in VAB. These differences may reflect variations in prior knowledge, learning readiness, or increasing familiarity with practicum procedures and assessment formats; however, because these factors were not directly measured, they cannot be considered definitive explanations. Given the one-group pretest-posttest design, baseline differences should be considered when interpreting posttest and N-Gain results. Moreover, differences between Practicum I and II should not be interpreted as statistically significant based solely on class means; inferential comparisons would require appropriate statistical testing using individual student scores.

Overall, Table 2 demonstrates that students entered the learning intervention with varying levels of initial SPS and that the descriptive pretest scores were generally higher in Practicum II than in Practicum I. These findings provide important baseline information for interpreting subsequent learning outcomes. However, the observed differences should not be interpreted as statistically significant or as evidence of differences in learning effectiveness between the two practicum activities unless supported by an appropriate inferential analysis. The increase in KPS scores across all classes studied is also presented in the diagram in Figure 1.

Figure 1 shows that the overall increase in students' KPS in practicum II was higher than in practicum I. This suggests that through repeated practicum activities, students become more practiced in implementing KPS, resulting in higher KPS scores. Based on the KPS indicators, the highest KPS pretest scores in both practicums I and II across all classes were for the indicators "formulating problems" and "formulating conclusions," while the lowest scores were for the indicator "making analyses" or interpreting data from investigations. The highest and lowest KPS pretest scores are presented in Table 3.

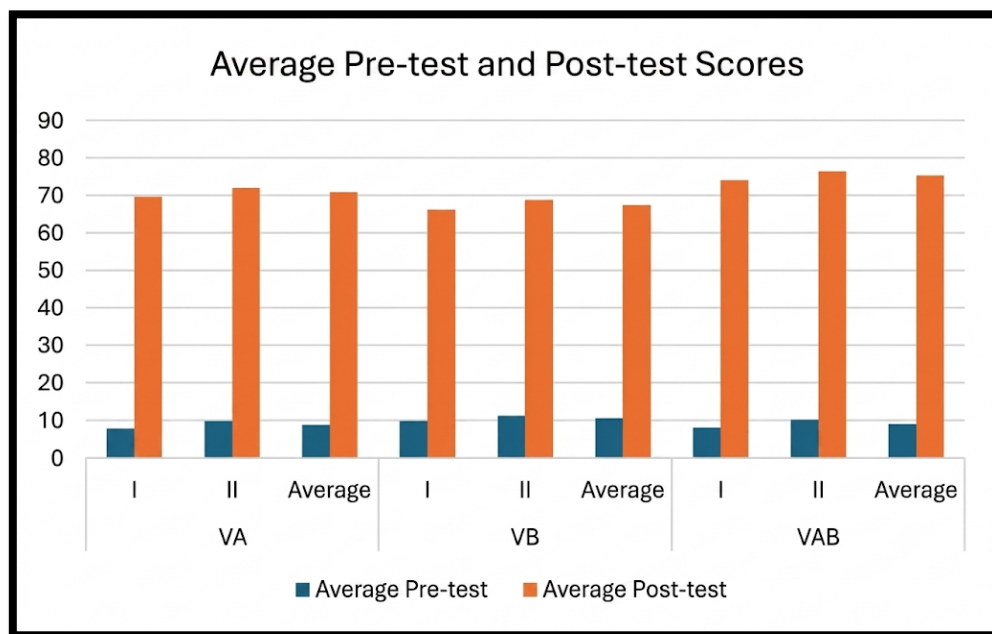


Figure 1. Diagram of Student KPS Improvement from Pretest to Posttest

Table 3. Average Pretest Scores for Several KPS Indicators (Range 0-100)

Class	Practical	Formulating the Problem	Formulating Conclusions	Conducting Data
VA	I	19.0	22.0	1.6
VA	II	23.0	25.0	3.1
VB	I	20.0	23.0	2.3
VB	II	23.0	23.0	2.0
VAB	I	17.0	19.0	1.6
VAB	II	20.0	23.0	1.6

The data in Table 3 can be interpreted as follows. In general, pretest scores for all Student Worksheet (KPS) indicators were still relatively low, with scores ranging from 1.6 to 25.0 on a 0–100 scale. This indicates that students had not yet fully mastered the KPS before the instruction. The indicator for formulating conclusions was higher than the indicator for formulating problems, except for the VB class for practical work II, which achieved similar scores. The KPS indicators for "formulating problems" and "formulating conclusions" obtained from research results were all still relatively low, but their scores were higher than the other KPS indicators. This is likely because students had read and studied the Student Worksheet (LKM) distributed one week before the practicum. Meanwhile, the indicator for "conducting data analysis" was difficult for students to understand because they had not yet conducted the practicum and therefore were unable to estimate the data they would obtain. This resulted in the lowest KPS scores for this indicator. However, in the pretest, all KPS indicators scored in the low category. Significant improvements in KPS in the posttest for each indicator studied were observed. The highest and lowest post-test KPS indicator values for practicums I and II were the same as those for the pre-test. The highest and lowest post-test KPS values are presented in Table 4 below.

Table 4. Mean Post-Test Scores on Several KPS Indicators (Range 0-100)

Class	Practical	Formulating the Problem	Formulating Conclusions	Conducting Data
VA	I	80.0	78.0	45.0
VA	II	81.0	83.0	48.0
VB	I	80.0	82.0	45.0
VB	II	84.0	82.0	48.0
VAB	I	92.0	89.0	45.0
VAB	II	94.0	97.0	47.0

Based on the data presented in Tables 3 and 4, all Science Process Skills (SPS) indicators showed an increase from pretest to posttest after the implementation of the CCDSR model assisted by practicum videos. However, the magnitude of improvement varied across indicators and classes.

The largest descriptive improvements were observed in the formulating problems and formulating conclusions indicators. The score for formulating problems increased from approximately 17.0–23.0 in the pretest to 80.0–94.0 in the posttest. Similarly, the formulating conclusions indicator increased from approximately 19.0–25.0 to 78.0–97.0. These results indicate that students showed substantial improvement in identifying problems and formulating conclusions after participating in the learning activities. The data analysis indicator showed the lowest posttest performance despite experiencing an increase from the pretest. The pretest scores ranged from approximately 1.6–3.1, while the posttest scores increased to approximately 45.0–48.0. Compared with the other indicators, this result indicates that data analysis remained the most difficult SPS component for students. Thus, although improvement occurred, students' ability to analyze and interpret experimental data was still relatively lower than their performance on other SPS indicators.

The results also show differences in SPS achievement between Practicum I and Practicum II. In general, the scores obtained in Practicum II were higher than those in Practicum I. Class VAB recorded the highest posttest scores on several indicators, particularly formulating problems (94.0) and formulating conclusions (97.0). Classes VA and VB also demonstrated improvement across the indicators, although their posttest scores were generally lower than those of Class VAB. The differences in improvement among the indicators indicate that the CCDSR model assisted by practicum videos did not produce an identical magnitude of increase for every SPS component. The most prominent descriptive improvement occurred in formulating problems and formulating conclusions, whereas data analysis showed the lowest posttest achievement. This variation provides an indication that students developed different SPS components at different levels during the intervention.

Overall, the results demonstrate a positive increase in students' SPS across all measured indicators following the implementation of the CCDSR model assisted by practicum videos. The improvement was particularly pronounced in the ability to formulate problems and conclusions, while data analysis remained the indicator requiring further improvement. However, the differences between indicators and practicum sessions are presented descriptively and should not be interpreted as statistically significant differences unless supported by indicator-level inferential analysis.

The findings demonstrate that the CCDSR model assisted by practicum videos was associated with substantial improvement in students' Science Process Skills (SPS) across the investigated classes. Classes VA and VAB achieved N-Gain values of 0.7, while Class VB obtained 0.6, indicating consistently positive development despite differences in the magnitude of improvement. This improvement can be explained by the sequential structure of CCDSR condition, construction, development, simulation, and reflection which progressively engages students in connecting prior knowledge with new concepts, observing experimental phenomena, designing and conducting investigations, and reflecting on experimental evidence. The condition stage provides scaffolding consistent with Vygotsky's Zone of Proximal Development, whereas the construction stage enables students to visualize experimental procedures before conducting investigations. Practicum videos are particularly relevant in this process because they provide accessible representations of complex experimental procedures and allow students to revisit important phenomena during learning (Miller, 2018; Smith, Johnson, & Brown, 2020; Zhou & Wang, 2019). The subsequent development, simulation, and reflection stages transform these visual experiences into active scientific inquiry by requiring students to conduct experiments, analyze evidence, communicate findings, and construct conclusions. This interpretation is consistent with previous evidence that video-assisted learning can improve SPS, engagement, and learning outcomes (Saprudin et al., 2021; Marinda et al., 2023; Ismail et al., 2025).

More importantly, the improvement was not uniform across SPS indicators. Formulating problems showed a substantial increase, from approximately 17.0–23.0 in the pretest to 80.0–94.0 in the posttest, while formulating conclusions increased from approximately 19.0–25.0 to 78.0–97.0. These findings suggest that the intervention particularly supported students' ability to transform observations into investigable questions and subsequently construct evidence-based conclusions. The practicum videos provided concrete visual representations of atomic spectra and energy quantization, allowing students to observe phenomena that are otherwise difficult to conceptualize through mathematical and verbal explanations alone. Within the CCDSR framework, students were not positioned as passive viewers; instead, they were required to identify problems, conduct investigations, interpret observations, and relate empirical evidence to theoretical concepts. This mechanism may explain the strong development of problem formulation and conclusion-making skills. The finding is consistent with Saprudin et al. (2019), who reported that simulation-based practicum videos in quantum physics supported SPS, particularly observation, data interpretation, and hypothesis formulation. It also extends previous research by demonstrating that integrating videos into a structured inquiry-oriented learning sequence can promote specific SPS components rather than merely improving SPS as a general outcome.

In contrast, data analysis remained the least-developed SPS indicator, increasing from approximately 1.6–3.1 in the pretest to 45.0–48.0 in the posttest. Although this represents considerable progress, the lower posttest

achievement compared with problem formulation and conclusion-making suggests that analyzing experimental evidence requires a higher level of cognitive integration. Students must simultaneously interpret numerical information, identify patterns, apply mathematical relationships, evaluate measurement results, and connect these findings with theoretical explanations. This challenge was evident in both practicum contexts. In the “Hydrogen or Neon Gas Spectra” practicum, students had to observe spectral lines and connect wavelength-related evidence with atomic spectra and photon energy, requiring observation and procedural competence (Huda, Sutopo, Rusilowati, & Indriyanti, 2021; Kurniasih & Aisyah, 2022), as well as the ability to evaluate quantitative evidence using theoretical principles (Mahmoudi, Rahimi, & Hosseini, 2020; Rizkiana, Apriani, & Khairunnisa, 2020). Similarly, the “Energy Quantization” practicum required accurate measurement (Budiyanto, Nugraha, & Sari, 2021), logical and mathematical reasoning (Mahmoud, El-Sayed, & Farouk, 2022), scientific problem solving (Hakeem, Khan, & Rahman, 2023), evaluation of experimental findings against theoretical predictions (Setyawati, Nugroho, & Prasetyo, 2020), and collaborative interpretation and communication of evidence (Wahyudi, 2021). Thus, the comparatively lower data-analysis performance indicates that visual and practical experiences alone may be insufficient without explicit scaffolding for quantitative interpretation.

The findings also contribute to the growing evidence supporting video-assisted and experimental learning in science education. Previous studies have demonstrated that video media can enhance student engagement, learning outcomes, and SPS (Putra et al., 2025; Nuha, Sari, Utomo, & Wahyuni, 2021; Gantina et al., 2024; Hafizah, 2020), while Al Martin (n.d.) specifically highlighted the potential of practicum videos in quantum physics learning. The present study advances this evidence by positioning practicum videos within the structured CCDSR learning process rather than using them merely as supplementary demonstrations. In this configuration, videos function as cognitive and procedural resources that support the transition from observing abstract phenomena to conducting investigations and constructing evidence-based explanations. Nevertheless, differences among classes should be interpreted cautiously. Although Classes VA and VAB obtained higher N-Gain values (0.7) than Class VB (0.6), and VAB achieved the highest posttest mean (75.3), these differences cannot be attributed to specific classroom characteristics because the study was not designed to compare classes experimentally. Variations in baseline ability, engagement, participation, or classroom dynamics may have contributed to these differences. Therefore, the findings provide stronger evidence for within-class SPS improvement than for comparative effectiveness among classes.

Pedagogically, these findings indicate that practicum videos are most valuable when embedded within learning activities that require students to actively formulate problems, investigate phenomena, evaluate evidence, and construct conclusions rather than simply watch experimental demonstrations. This approach is particularly relevant to abstract Quantum Physics topics such as atomic spectra and energy quantization, where students must connect mathematical and theoretical representations with observable experimental evidence. The comparatively weak performance in data analysis also provides a specific direction for improving the CCDSR intervention: lecturers should incorporate guided data-analysis worksheets, explicit modeling of quantitative reasoning, connections among graphs, mathematical equations, and physical interpretations, and repeated opportunities to evaluate experimental evidence. These implications should nevertheless be considered within the study’s methodological limitations. The one-group pretest-posttest design without a control group does not permit the observed gains to be attributed exclusively to the intervention, and the participants were drawn from one Physics Education Study Program, limiting generalizability. Future research should therefore employ controlled or comparative designs across broader populations and examine which CCDSR components contribute most strongly to individual SPS dimensions. Overall, the study contributes evidence that integrating practicum videos with CCDSR can support SPS development while revealing that higher-order skills, particularly data analysis, require more targeted instructional scaffolding.

Conclusions

This study demonstrates that the CCDSR model assisted by practicum videos is effective in improving students’ Science Process Skills (SPS) in learning atomic spectra and energy quantization. The improvement was consistently observed across the three classes, with N-Gain values of 0.7 in Classes VA and VAB and 0.6 in Class VB, indicating high and moderate improvement, respectively. The intervention particularly supported students’ abilities to formulate problems, develop hypotheses, identify variables, and formulate conclusions, although data analysis and interpretation remained comparatively less developed. These findings suggest that integrating practicum videos within the structured stages of the CCDSR model can facilitate students’ active engagement in scientific inquiry and help connect experimental evidence with abstract concepts in Quantum Physics. Therefore, the CCDSR model assisted by practicum videos represents a promising instructional

approach for strengthening SPS, while additional scaffolding for data analysis is recommended to achieve more balanced development across all SPS indicators.

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