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The holistic effect of nature of science and science process skills on students' conceptual and procedural knowledge and motivation within the context of modified guided discovery in physics laboratory

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Abstract
Literature emphasizes integrating nature of science (NOS), science process skills (SPS), and varied laboratory activities within guided discovery methods to enhance learning, yet empirical evidence on their synergistic effects remains scarce. This study involved a phase III tandem design with three treatment pair match groups, using a quasi-experimental approach and assessed the combined impact of *modified guided discovery methods* using implicit NOS integration, explicit approach of SPS, and diverse labs on academic achievement (conceptual/procedural knowledge) and motivation among 88 Ethiopian college students. ANCOVA and multiple regression analyses showed non-significant individual effects for NOS (*p* = 0.702 on conceptual, 0.842 on procedural, 0.986 on motivation), pedagogy (*p* = 0.830, 0.635, 0.759), and SPS (*p* = 0.568, 0.880, 0.952) on conceptual, procedural, and motivation, respectively. Interaction effects (NOS, SPS, and pedagogy) were also non-significant across outcomes (*p* > 0.05). However, substantial Partial eta-squared values indicated meaningful practical effects: individually, NOS (η^2 = 0.865 on conceptual, 0.815 on procedural, 0.658 on motivation) and SPS (η^2 = 0.894 on conceptual, 0.788 on procedural, 0.724 on motivation) strongly influenced outcomes; interactively, NOS*SPS had large effects on conceptual knowledge (η^2 = 0.711) and moderate effects on procedural knowledge (η^2 = 0.521) and motivation (η^2 = 0.524). This divergence between statistical non-significance and large effect sizes suggests the instructional model meaningfully impacts learning despite null hypothesis test results. We recommend: (1) curricular refinements to amplify effects, (2) application in diverse learning environments, and (3) supplementing traditional assessments with performance-based evaluations to better capture gains.

Keywords: modified guided-discovery, motivation, physics laboratory, nature of science, process skills

INTRODUCTION

The paramount focus of 21st century research is the thorough comprehension of science education concepts by students. Currently, research indicates that the prevailing teaching and learning approach prioritizes rote memorization of factual information for exam success (Abate et al., 2020; Abate & Mishore, 2024) and the acquisition of extensive information (Nehm & Schonfeld, 2007; Zeidan & Jayosi, 2015). The Ethiopian education system heavily emphasizes lecturing and demonstration for the acquisition of factual knowledge (Abate et al., 2020; Alemu et al., 2019) while neglecting real-life contextual learning (Teferra et al., 2018), that leading students away from practical learning and confining them to artificial classroom environments, textbooks, structured manuals, and course modules. Additionally, science education research identified that many students are falling short of expected learning outcomes in science, indicating a lack of fundamental

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Contribution to the literature

- Develops and implements a novel model guiding educators in explicit/implicit integration of NOS and PPS within laboratory courses.
- Transforms student learning from rote procedural execution to critical scientific engagement, fostering question-driven inquiry, conceptual understanding, and defense of scientific knowledge.
- Provides the first unified approach to synergistically embed generic science laboratory components (NOS, PPS, guided discovery, lab formats) within a single instructional design.

content knowledge, understanding of natural phenomena, procedural skills for evidence collection, and the ability to justify scientific claims and comprehend the nature of science (Daniel & Lemma, 2021; Kind & Osborne, 2017). This has been an enduring concern for science educators and researchers in the area (Kind & Osborne, 2017). The scientific community is actively debating about the development and teaching of scientific knowledge as it appears that students and teachers alike lack a clear understanding of how scientific knowledge is constructed and applied in the classroom (Badmus & Jita, 2022; Schizas & Psillos, 2019). One potential explanation for this gap could be the limitations on development, selection, and implementation of generic components of science education. Due to these limitations, the influence of the load was on the shoulders of teachers teaching science in schools and colleges when conducting science laboratory activities and delivering practical activities (Adisu et al., 2021; Daniel et al., 2021).To this end, research has demonstrated that the guided discovery models are effective in scientific learning and improving learning outcomes (Shahali et al., 2017) when incorporated in the context of science process skills (SPS) and nature of science (NOS). The modified guided discovery approach better strengthens the attachment of teacher and students in the process of learning by minimizing students' dependence on cocked textbook and structured laboratory activities (Daniel et al., 2021).

In science education, laboratory work holds great importance, because it enables students to comprehend science, construct alternative knowledge, SPS, and engage in diverse learning environments (Hayward, 2003; Zudonu & Njoku, 2018). When it properly executed, it becomes a student-centered approach that requires active participation from students (Hayward, 2003). Students encounter real-life scenarios in the laboratory and gain hands-on experience in experimentation, analysis, and conceptual learning. Additionally, it contributes to students' motivation, comprehension of the fundamentals of physics (science), and formation of well-informed perspectives on the NOS (Baloyi et al., 2017; National Research Council, 2012). Therefore, to enrich students' science education, the fundamental elements of laboratory activities should be thoughtfully selected, integrated, and incorporated into both school and college curricula (Daniel et al., 2023a). Science laboratory materials should contain SPS, concepts, procedures, NOS, alternative pedagogy, appropriate forms of laboratory, and assessment methods (Hofstein & Lunetta, 2004; McDermott, 2013) to achieve the desired student learning outcomes. When these fundamental components are being properly integrated and implemented, students can gain authentic insight into the work of scientists as they explore scientific findings, such as theories, laws, and principles. Hodson (2002) suggests that this integration fosters student learning and understanding of the NOS and process skills. Despite their importance, the different types of fundamental components and the methods for selecting, integrating, and using them in science education are less well known and properly implemented globally. There are limitations of the previously used curriculum materials and research works in science education in the selection, integration, and implementation of basic science components. Hence, the field requires a new alternative learning approach that guides the choice, integration, and application of fundamental elements in science instruction. In this study, the alignment of basic components was shown to demonstrate various knowledge construction models employed in physics laboratories (see **Appendix A**). The basic components were selected, integrated, and implemented following a literature review that identified gaps in the area of physics/science laboratory work within the same study (see Adisu et al., 2021; Daniel et al., 2023a).

In science education, NOS and PPS are the basic components to be integrated to facilitate and enhance student learning of science. The studies indicated that NOS and SPS have revealed a positive correlation between NOS, SPS, concepts, and motivation (Areepattamannil et al., 2011; Kara & Aslan, 2025; Mesci et al., 2023). The NOS refers to the epistemological and socio-cultural foundations of scientific knowledge, which encompass its tentativeness, empirical basis, creativity, and cultural embeddedness (Lederman, 2007; Osborne et al., 2003). Similarly, practicing process skills (PPS) represents the procedural skills or a series of actions essential for scientific inquiry, so they integrate either their basic components (e.g., observation, classification) or integrated process skill components (e.g., hypothesizing, experimenting) (Chabalengula et al., 2012). Each NOS component and PPS activity has a role in the learning of science (Badri & Shri, 2013). So they have to be properly and clearly integrated into the school or college curriculum based on students' cognitive developmental stage. There are debates in implicit or explicit approaches of NOS and PS and their understanding (Mesci et al., 2023), but their individual and interaction effects are less studied on students' conceptual and procedural knowledge, and motivation . In this study, NOS implicitly integrated, and PPS explicitly presented before start laboratory work, and assessed to measure its holistic effects on students' achievement and motivation.

When conducting scientific educational research in laboratories, there are multiple research directions in the science literature. Most of these focus on implementing specific teaching methods such as conventional vs guided discovery, and free discovery and their impact on students' motivation and academic performance (Baloyi et al., 2017; Hayward, 2003; Leung et al., 2017). Others (Abrahams, 2009; Bell, 2008; Holmes et al., 2017; Parreira & Yao, 2018; Ramarian, 2016) have compared the effects of different laboratory setups such as structured vs semi-structured and open form on students' academic performance and motivation. While the majority of research in science laboratories involves the implicit vs explicit inclusion of NOS and SPS and debates on it (Baloyi et al., 2017; Kalman et al., 2018). Only a few studies have focused on the content analysis about the inclusion of NOS, PS of science and physics laboratory materials development and the evaluation of hands-on experiments and development of tools and models/ conceptual framework (Blosser, 1980; Huang et al., 2021; Singh, 2014).

Content assessments of laboratory work reveal that many studies have not incorporated essential elements into science textbooks, and laboratory experiments or provided adequate explanations for students' abilities and motivation (Hofstein & Lunetta 2004; Huang et al., 2021; Singh, 2014). Shimeles (2010) performed a content analysis of physics laboratory materials and discovered disparities between actual learning in laboratory classes and learning objectives, as well as a lack of attention to affective factors such as attitudes and motivation. Additionally, the materials were designed to be content-focused and tailored for traditional techniques and confirmatory laboratory procedures. Also the high school curriculum materials indicated less well defined and integrated form of NOS, PPS, and instructional models to present the science components (Huang et al., 2021). Another observation made by (Blosser, 1980; Daniel et al., 2023a) indicated that the majority of laboratory studies lack a conceptual framework to guide their investigations. In addition to the above implications in the area, the overall review indicates that all of the previous studies have deficiencies in the selection, integration, and application of the aforementioned fundamental elements in science and physics laboratory work.

In response, a review of the literature on the identified deficiencies was conducted as part of the same project, and alternative models (including selection, integration, and implementation) of generic components such as NOS, PPS, contents, forms of laboratories, pedagogies, and assessment methods were formulated and put into practice (Daniel et al., 2023a). Based on analysis of theoretical and empirical findings on the philosophical foundations of educational theories, pedagogies, and curriculum development strategies, the project proposes the following conceptual models for integrating core components of science education laboratories:

(1) Scientific knowledge development in labs using structured content with controlled lab conditions;

(2) Scientific knowledge development in labs using structured content with uncontrolled lab conditions;

(3) Scientific knowledge development in labs using semi-structured content and controlled lab conditions;

(4) Scientific knowledge development in labs using open content and open lab conditions.

Each model constitutes a specific combination of curriculum structure and lab environment.

To this end, this Daniel et al. (2023a) developed five alternative models of learning that guide the selection, integration, and implementation of generic components in science/physics laboratory work. These are structured guided discovery (SGD), semi-structured guided discovery (SSGD), scaffolding guided discovery (SCGD), and traditional and free discovery methods. SGD employs rigidly designed curricula with open-ended labs, while SSGD blends structured prompts with controlled experiments. SCGD combines semi-structured guidance with adaptive lab formats, emphasizing meta-cognitive scaffolding (Daniel et al., 2021). These methods address cultural and procedural gaps in science education (Daniel et al., 2021; Kalman et al., 2018). In the model, NOS implicitly embedded in problem-solving tasks and PPS explicitly taught. Pedagogical and lab-orientation perceptions measured as covariates further contextualize outcomes (Abrahams & Saglam, 2010; Daniel et al., 2021). The three models, SGD, SSGD, and SCGD, detail descriptions about constructs and are systematically linked to the survey presented to enhance reproducibility and theoretical coherence (see **Appendix A**).

Except for free discovery models, the other four were models tested in a series of previous studies. These models can be used in science lab work and serve as alternative models for determining and selecting variables in science lab work. But, in this study the independent and interaction effect of three modified

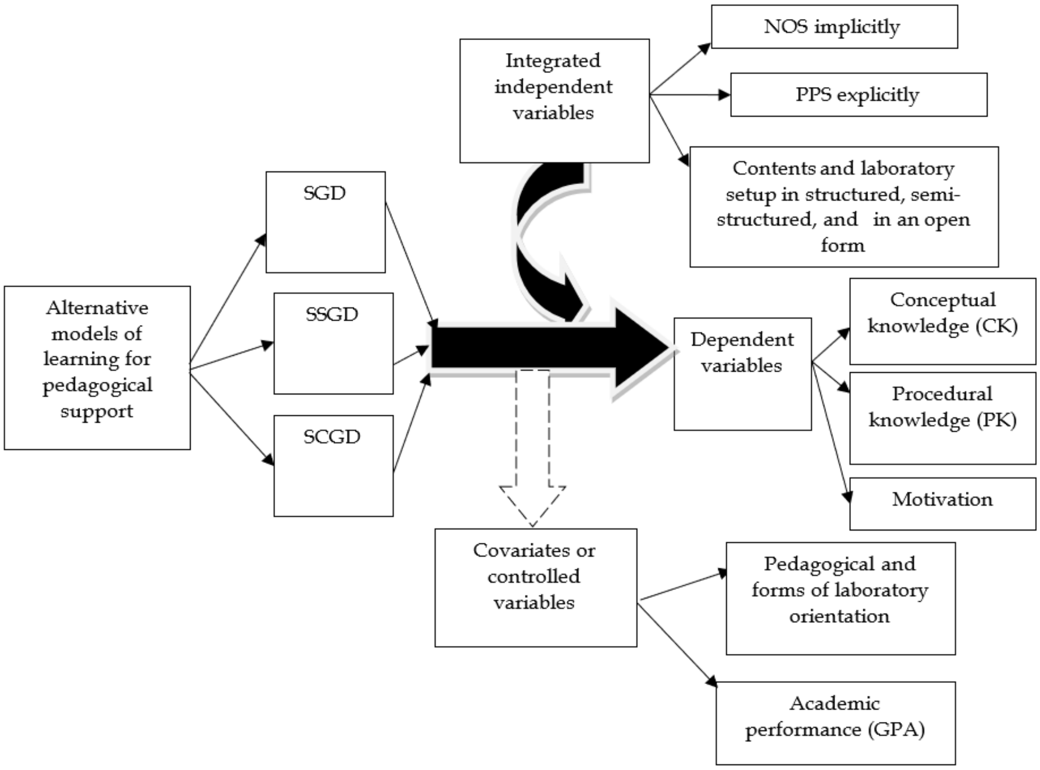

Figure 1. A conceptual framework that depicts the relationship among independent, covariates, and dependent variable of the study (Daniel et al., 2023a)

guided discovery methods (SGD, SSGD, and SCGD) in combination with NOS, and PPS result was reported. The initial part of the implementation results including data from the control group, was reported by Daniel et al. (2021), indicating that procedural knowledge and academic performance had a more direct impact on conceptual knowledge. Additionally, using different teaching methods, conceptual knowledge and academic performance had a direct impact on procedural knowledge. Similarly, the impact of procedural knowledge and PPS in the physics laboratory had a direct effect on motivation. The second part of the results, reported by Adisu et al. (2021), found that all modified guided-discovery methods had a significant difference in pre-/post-test in procedural and conceptual knowledge and motivation. Daniel et al. (2023b) discovered that the groups were significantly different in terms of conceptual and procedural knowledge and motivation, but similar in their views of the NOS. However, there has been no previous investigation into how the integrated components independently and/or in interaction affect learning outcomes such as conceptual and procedural knowledge and motivation. This means that there have been no investigations into the effects of lab components such as process skills, views of NOS, and pedagogy as input variables and students' academic performance and their pedagogical orientation (mindset or experience) as a control variable on students' learning outcomes such as conceptual and procedural knowledge and motivation. Therefore, this study aims to investigate the individual and interaction effect of pedagogies, views of NOS, and PPS while controlling for overall academic performance and pedagogical orientation on conceptual and procedural knowledge, and motivation (limited to modified guided-discovery method). To achieve this, the following research questions guided the study:

1. What is the interaction effect (independent and combined) of NOS, SPS, and pedagogy on conceptual knowledge with control of covariates? As indicated in **Figure 1**, how dependent variables (CK) is influenced by independent factors *implicit integration of NOS* (arrow from NOS), *explicit training of PPS* (arrow from PPS), and laboratory activity contents and by support of *guided-discovery pedagogy* (SGD/SSGD/SCGD pathways) and moderated by control variables of *pedagogical orientation* and academic performance GPA (dashed line).
2. What is the interaction effect (independent and combined) of NOS, SPS, and pedagogy on procedural knowledge with control of covariates? As indicated in **Figure 1**, how dependent variables (PK) is influenced by independent factors *implicit integration of NOS* (arrow from NOS), *explicit training of PPS* (arrow from PPS), and laboratory activity contents and by support of *guided-discovery pedagogy* (SGD/SSGD/SCGD pathways) and moderated by control variables of *pedagogical orientation* and academic performance GPA (dashed line).

3. What is the interaction effect (independent and combined) of NOS, SPS, and pedagogy on motivation with control of covariates? As indicated in **Figure 1**, how dependent variables (motivation) is influenced by independent factors *implicit integration of NOS* (arrow from NOS), *explicit training of PPS* (arrow from PPS), and laboratory activity contents and by support of *guided-discovery pedagogy* (SGD/SSGD/SCGD pathways) and moderated by control variables of pedagogical *orientation* and academic performance GPA (dashed line).

CONCEPTUAL FRAMEWORK

The systematic reviews highlight the persistent challenges and evolving debates in teaching the NOS and PPS in physics laboratories. While foundational works (e.g., Lederman, 2007; Osborne et al., 2003) established NOS as critical for scientific literacy, however recent studies reveal gaps in its integration (Huang et al., 2021), particularly in physics labs (Daniel et al., 2023a). For instance, Daniel et al. (2021) found that explicit NOS instruction especially when coupled with guided-discovery methods significantly enhances conceptual understanding, but cultural and curricular disparities often dilute its significant impact. Similarly, Adisu et al. (2021) demonstrated that scaffold PS approaches (e.g., hypothesis-driven labs) improve procedural knowledge, though contradictory findings emerge regarding their efficacy in diverse educational settings. A meta-analysis by Daniel et al. (2023a) further underscored the role of structured vs inquiry-based labs, showing that SSGD strikes an optimal balance for NOS and PPS integration, while fully open-ended methods (e.g., SCGD) risk overwhelming novice learners. These studies align with broader critiques (e.g., Kalman et al., 2018) about the lack of standardized frameworks for NOS and PPS in physics curricula, emphasizing the need for context-sensitive pedagogies.

The debate encompasses the implicit versus explicit integration of NOS and process skills (PS), as well as their assessment methodologies. Recent systematic reviews (Daniel et al., 2023a; Daniel & Lemma, 2021; Huang et al., 2021) advocate for mixed-method approaches (e.g., Likert-scale surveys combined with performance tasks) to holistically capture NOS and PS competencies. For instance, Daniel et al. (2021) linked specific NOS subcomponents (e.g., tentativeness and theory-leadenness) to guided-discovery variants (SGD, SSGD, and SCGD), revealing that implicit NOS embedding (as in SGD) enhances motivation, while explicit PS training (as in SCGD) improves procedural accuracy. Nevertheless, contradictions persist: studies such as Ramarian (2016) report minimal gains from NOS-focused labs in low-resource settings, highlighting the mediating role of teacher orientation and laboratory structures (Abrahams & Saglam, 2010). This study addresses these gaps by testing modified guided-discovery models (Adisu et al., 2021) featuring explicit PS scaffolding and implicit, activity-based NOS integration, while controlling for pedagogical orientations, a variable frequently overlooked in prior meta-analyses (Daniel et al., 2023a). By situating our design within these contemporary debates, we aim to reconcile conflicting evidence and advance evidence-based practices in physics education.

These discrepancies may stem from divergent cultural perspectives regarding science, the NOS, PPS, pedagogical/laboratory orientation, and resource availability (Daniel et al., 2023a; Huang et al., 2021; Mesci et al., 2023). Such contextual factors encourage transparent reporting of both positive and negative findings. Historically, Ethiopia's educational system, particularly science education, integrated cultural practices, leading to limitations in foundational science education integration (Areaya, 2008). Consequently, direct comparison of curriculum implementation outcomes with other countries is problematic. To address these challenges, this study selects, integrates, and implements diverse approaches to content, NOS, PS, and laboratory formats under a modified guided-discovery framework. Conducted in teacher education colleges with pre-service teachers key facilitators of children's knowledge acquisition the research emphasizes laboratory-based application of integrated pedagogical and scientific components, prioritizing practical engagement over theoretical instruction.

Laboratory activities play a crucial role in the development of students' practical skills, ability to observe and describe physical phenomena, motivation, creativity, problem-solving skills, and critical thinking (Babalola & Ojobola, 2022; Babalola et al., 2022). According to these studies, such activities can also aid in students' development of conceptual understanding and scientific perspectives about the NOS. It is important to explore how students can enhance various types of scientific knowledge and their interest in science, as well as SPS (Nawaz, 2022). Researching and creating diverse learning models and integrating hands-on activities into science classroom instruction are some approaches to achieve this. But, the diversified science activities challenges the applicability in certain limited culture, resource, etc. Research has identified several challenges in using practical activities in science education, including a lack of instructional resources, limited alternative learning models for science labs, ambiguous attitudes toward practical activities, inadequate teacher training and professional development, and rigid procedures for students to follow (Babalola & Ojobola, 2022; Babalola et al., 2020, 2022). Scholars are actively working on developing alternative laboratory models to address these issues. The models developed in this study aim to assist and directs educators how to explicitly or implicitly integrate components in developing and conducting lab courses, while also enabling students to ask questions, grasp new concepts, and foster a scientific mindset that encourages independent inquiry and defense of scientific knowledge, rather than just following manual procedures (Daniel et al., 2023a).

It was suggested that these laboratory-learning models need to incorporate NOS, and SPS in the context of guided discovery method to promote learning (Daniel et al., 2023a). This is because understanding the NOS and process skills are crucial for students' higher level knowledge such as meta-cognitive level knowledge (Schunk, 2012) as they encompass a comprehensive understanding of the concepts and methods taught in science. Therefore, educational researchers have long considered the grasp of NOS and process skills as an essential aspect of teaching and science literacy (Lederman, 2007, 2011). The primary components of NOS as mentioned above in various research studies include the tentative nature of scientific knowledge, the role of observations and inferences, and the balance of subjectivity and objectivity within scientific disciplines. Additionally, key aspects such as creativity and rationality in scientific thought, as well as the interplay of imagination and logical reasoning, are significant. Furthermore, the social and cultural contexts surrounding science play a crucial role. Scientific theories and laws, along with the methods employed in scientific investigations whether they are a single universal approach or a range of varied methods are also essential components (Abd-El-Khalick et al., 2002; Aikenhead & Ryan, 1992; Osborne et al., 2003). In addition; SPS are a series of activities that have been refined through participation in scientific research (Mutlu & Temiz, 2013). So they are also the main generic components of physics laboratory. Because the practice of process skills involves conducting experiments, recording observations, making measurements, and presenting data obtained from experiments (National Research Council, 2012). In their work, Chabalengula et al. (2012) and Badri and Shri (2013) delineate the basic scientific processes as observation, classification, measurement, inference, scientific thinking, forecasting, and communication. In similar vein, integrated SPS encompass graphing, hypothesizing, interpreting information, developing models, experimenting, and defining operationally. Therefore, in science education, the practice of these process skills is pivotal in acquiring and developing scientific knowledge or participating in guided discovery activities. This study assessed all 14 components of SPS using a pen and pencil format by converting them into rated scale questions. The main objective of this study was to investigate the effects (independent and interaction) of the implicit approach of NOS and the explicit approach of PPS on conceptual and procedural knowledge and motivation by employing a modified guided discovery method.

The earlier version of the research project developed five distinct learning models to provide a framework for selecting, integrating, and applying generic components in science and physics laboratory work (Daniel et al., 2023a). These models were based on a comprehensive review of educational philosophies and learning theories from a previous version. In order to account for the previously mentioned concerns, this study employed three modified guided discovery models of learning such as SGD, SSGD, and SCGD as reported by (Authors3, 2023). Hence the models were used to measure the independent and interaction effects of the NOS, PPS, and pedagogies (SGD, SSGD, and SCGD) on students' conceptual and procedural knowledge, and motivation by controlling pedagogical orientation/perception and overall academic performance (GPA) on third year physics students in teachers colleges. **Figure 1** illustrates this combination and acts as the conceptual basis for the present research.

METHODOLOGY

Design of the Study

The study used the same research design as in previous versions (see Adisu et al., 2021; Daniel et al., 2023b). It involved a phase III tandem design with three treatment groups, using a quasi-experimental approach (Campbell & Stanley, 2005). This design was chosen to compare three-paired match treatment groups (SGD, SSGD, and SCGD) and measure the independent and interaction effects of independent variables on dependent variables with control of some selected covariates.

Method of the Study

The study utilized to measure the association and /or correlation of independent with dependent variables while controlling for covariates (Creswell & Plano Clark, 2017). The ANCOVA test and multiple regressions were employed to measure the effects. Students' conceptual and procedural knowledge and motivation used as dependent variable and different perspectives of NOS, PPS and modified guided discovery pedagogies used in each group were used as independent variables, while controlled variables were pedagogical orientation/perceptions and overall academic performance.

Population and Samplings

The study used the same population and sampling method as Daniel et al. (2023b). The study selected two comparable teacher colleges (Arbaminch and Hossana) in Ethiopia's Southern nation nationalities and people regional government via convenience sampling, by prioritizing facility conditions, aligned curricula, material resources availability, and instructor expertise.

Table 1. Number of participants per the implemented design

College	Number of participants per group					
	SGD		SSGD		SCGD	
	M	F	M	F	M	F
Arbaminch College of Education	23	9	20	7		
Hossana College of Education					26	3
Total	32		27		29	

Both colleges offered science laboratory technician programs, ensuring adequate infrastructure for physics experiments, and employed master's-level instructors with 15+ years of experience in lab instruction, module course development, and evaluation. Purposive sampling identified third-year pre-service physics students (N = 88; age > 19; 69 male, 19 female) due to their advanced lab experience: their curriculum included six hands-on laboratory activities, with the study's experiment positioned as the final task. This cohort had prior exposure to process skills, NOS concepts, and pedagogical training, unlike first- or second-year students.

Within each college's there are two third-year groups, random sampling assigned treatments: SGD (n = 32; 23 male, 9 female) and SCGD (n = 29; 26 male, 3 female) to Arbaminch College and SSGD (n = 27; 20 male, 7 female) to Hossana College (220 km apart). To minimize cross-group contamination, experiments were conducted simultaneously, with experiment titles withhold until sessions began. Classroom teachers verified preliminary data to ensure integrity. The colleges' comparable resources (equipment, technician support) and instructor qualifications (all master's-trained with similar teaching loads) bolstered internal validity, though gender imbalance (22% female participation) reflects regional enrollment trends (see **Table 1**).

Data Gathering Procedures and Treatments

The research was conducted in compliance with Addis Ababa University's ethical guidelines and regulations. Before the intervention, college instructors and participating students were presented with a cooperative letter from Addis Ababa University and signed a formal informed consent agreement with the first author. Additionally, participants were briefed on the research procedures, potential risks and benefits, and the voluntary nature of their involvement. Subsequently, an assessment of the facilities at two colleges was carried out. Teachers participating in the three modified guided-discovery approaches received training, which focused on discussions of various learning models, physics laboratory pedagogies, forms of laboratories that fit the pedagogy, content presentation, NOS, questioning techniques, answer provision, and impact assessment of variables. The study conducted in the formal class and schedule of the college. Tools and lesson plans were developed and validated before the intervention. A pre-test of the study design was conducted before the intervention. Teachers and students received ongoing formative and supportive feedback during the intervention period through the distribution of checklists and reporting formats for each experimental task. First-level data analysis and responses to selected questions were completed and signed by the class teacher to reduce within-group contamination before and after the studies. Upon arrival, the experimental groups were informed of the experiment titles for the following session, rather than beforehand to minimize within group contamination in the same college. Over the 16-weeks academic semester, a total of seven experiments/activities were conducted within ten weeks. These experiments included charging body and charges, series and parallel direct current circuits, verification of Kirchhoff's law, Ohm's law and electrical resistance determinations, internal resistance and electromotive force of dry cell, and determination of induced electromotive force in a solenoid. The study design was implemented, followed by a post-test.

Data Collection Tools

The variables of the study were measured using adjusted tools after identifying the dependent, independent, and control factors based on the models introduced (Daniel et al., 2021). Semi-structured and scaled instruments were adapted from Liang et al. (2006) to evaluate students' perspectives on NOS and PS. However, the scaled quantitative data reported in this article. The components used to measure NOS were tentativeness of scientific knowledge, observations and inferences, subjectivity and objectivity in a scientific discipline, creativity and rationality in science or imagination and logical reasoning, and social and cultural embeddedness in science. In addition, scientific theories and laws, scientific methods were used in scientific investigations. The 14 basic and integrated PS used in this study were observation, classification, communication, record data, estimate, infer, predict, identify variables, control variables, interpret, form hypotheses, investigate, use models, and create graphs. They were converted to rated scale questions, and also motivation questions were adapted and modified, pedagogical orientation/perception developed based on the study context and validated. Following the approach outlined by Hofstein and Lunetta (2004), the tools used to measure procedural and conceptual knowledge were created and verified within the context of laboratory activities. The study's environment influenced the creation and validation of questions related to pedagogy and laboratory orientation. Furthermore, the college registrar's office provided the cumulative grade point average of the students.

Tool Validation

Prior to implementation, all study instruments underwent pilot testing. While conceptual and procedural knowledge tests used in physics laboratories should be context-based and therefore may not require standardization (Hofstein & Lunetta, 2004), a pilot study was conducted to collect and refine the questions. Based on the findings, some questions were modified. An assessment was conducted using a Likert scale ranging from 1 to 5. A score of 1 indicated "strongly disagree", 2 indicated "disagree", 3 indicated "uncertain", 4 indicated "agree", and 5 indicated "strongly agree" for NOS and motivation. For PPS, a scale from 1 to 4 was used, with 1 indicating "never", 2 indicating "sometimes", 3 indicating "usually", and 4 indicating "always". The reliability of the Likert scaled questions was assessed using Cronbach's alpha. The internal consistency (reliability) of the conceptual and procedural tests was confirmed using Kuder-Richardson KR20. Based on the reliability test, all Likert scale instruments demonstrated both reliability and fell within an acceptable range. The Cronbach's alpha for the test was within the acceptable range ($\alpha > 0.7$) as per Nunnally and Bernstein (1994). Furthermore, the results of the cognitive tests were within an acceptable range according to Cortina (1993). Data analysis methods were selected based on variable types and after verifying the assumptions for parametric versus non-parametric tests. For this study, we conducted assumption testing for ANCOVA and regression analyses, reporting only those results relevant to the article's scope. In previous iterations of this project (Daniel et al., 2021, 2023b), we fully documented all diagnostic tests including homogeneity of regression slopes, Levene's test for equality of variances, multicollinearity assessments, and post-hoc power analyses to contextualize different findings.

To ensure the validity of the tests, including face, content, and construct validity of the questions, the study enlisted the participation of two English and Amharic language instructors and three physics instructors from the colleges of teacher education. The selection criteria required participants to have work experience in college and a master's degree in education. To validate conceptual and procedural items, the phi coefficient (ϕ) was used to compare the responses of three physics instructors in colleges with those of the researcher, resulting in the highest correlation factor of 0.78. Nonetheless, items were adjusted based on low correlation values.

Statistical Analysis Techniques

The study utilized the ANCOVA test and multiple regression to analyze the independent and interaction effects of independent variables on dependent variables while controlling selected covariates. Prior to testing the hypothesis, the skewness test, also known as the normality test, was conducted. According to Ramos et al. (2018), the data is parametric and meets the assumptions, such as being skewed within the range of $-1 < \text{skewness} < 1$ (Ramos et al., 2018) or $-2.58 < \text{skewness/standard error} < 2.58$ (Ghasemi & Zahediasl, 2012), thus a parametric test was performed. SPSS version 22 was used for this analysis.

Variables of the Study

The variables considered in the study as presented in conceptual map design in **Figure 1**, such as teaching methods (SGD, SSGD, and SCGD), course content (including both conceptual and procedural knowledge), views of the NOS in implicit approach, and SPS in explicit approach were the independent factors. Three elements, including conceptual and procedural knowledge, and motivation, were regarded as the outcomes of interest, while the overall academic performance and the perception/orientations to teaching and laboratory work were treated as control factors. Details on how the study's control factors and outcomes were utilized can be found in Daniel et al. (2023b).

RESULTS

This part focuses on presenting, analyzing, and interpreting the research findings to address the fundamental research inquiries of the study. As a result, various alternative learning models, NOS, and PPS effects were measured on dependent variables with control of some selected covariate variables.

Effects of NOS, PPS, and Pedagogies on CK

Table 2 displays the impact of NOS, pedagogy, and PPS on conceptual knowledge. The results indicate that the individual effects of NOS ($p = 0.702$), pedagogy ($p = 0.830$), and PPS ($p = 0.568$) on conceptual knowledge are not statistically significant. However, the relative effects of the independent variables are noteworthy, with partial eta-squared = 0.865 (86.5%) for NOS, 0.894 (89.4%) for PPS, and 0.018 (1.8%) for pedagogy. Among these, PPS has the largest effect, followed by NOS, while pedagogy has a smaller effect. Furthermore, the interaction effects of NOS*PPS ($p = 0.729$) and NOS*pedagogy ($p = 0.822$) are also deemed statistically insignificant. However, the partial eta-squared values of NOS*PPS (0.711 or 71.1%) and NOS*pedagogy (0.02 or 2%) are notable. Additionally, the interaction effects of PPS*pedagogy and NOS*PPS*pedagogy are negligible.

Table 2. Effects of NOS, pedagogy, and PPS on conceptual knowledge

Source	Type III sum of squares	df	Mean square	F	p	Partial eta-squared
Corrected model	297.457[a]	84	3.541	.974	.615	.965
Intercept	1.313	1	1.313	.361	.590	.107
GPA	.082	1	.082	.023	.890	.007
Pedagogical orientation	.005	1	.005	.001	.972	.000
NOS	70.165	25	2.807	.772	.702	.865
PPS	91.756	24	3.823	1.052	.568	.894
Pedagogy	.198	1	.198	.055	.830	.018
NOS * PPS	26.827	11	2.439	.671	.729	.711
NOS * pedagogy	.218	1	.218	.060	.822	.020
PPS * pedagogy	.000	0	.	.	.	.000
NOS * PPS * pedagogy	.000	0	.	.	.	.000
Error	10.906	3	3.635			
Total	2,390.000	88				
Corrected total	308.364	87				

Note. R^2 = .965 (adjusted R^2 = -.026) & the covariates appearing in the model are evaluated at the following values: GPA = 2.6469, pedagogical orientation = 16.4205 with the mean of dependent variable of conceptual knowledge 4.791

Table 3. Regression for conceptual knowledge as function of NOS, pedagogy, and PPS

Analysis of variance

Model		Sum of squares	df	Mean square	F	p
1	Regression	.337	3	.112	.031	.993
	Residual	308.026	84	3.667		
	Total	308.364	87			

Variables in the equation

Model		Mean	Unstandardized coefficients		Standardized coefficients	T	p	r
			B	Standard error	Beta			
1	(Constant)		5.269	1.623		3.246	.002	
	CK	4.8636						1.00
	NOS	56.1477	-.004	.025	-.018	-.164	.870	-.019
	Pedagogy	.6364	.044	.426	.011	.102	.919	.008
	PPS	28.4205	-.007	.030	-.026	-.236	.814	-.026

To measure the effect of each independent variable on the average of the dependent variable (conceptual knowledge), a multiple regression analysis was conducted.

Table 3 illustrates the regression for conceptual knowledge based on NOS, pedagogy, and PPS. The combined impact of NOS, pedagogy, and PPS on conceptual knowledge resulted in an R-squared (R^2) value of 0.001, with an adjusted R^2 value of -0.035. The equation to calculate the R^2 percentage is as follows: R^2 percentage = $(B_{nos} * r_{nos} + B_{peda} * r_{peda} + B_{pps} * r_{pps}) * 100\%$. Substituting the values, 0.001 * 100% = (-0.018 * -0.019 * + 0.011 × 0.008 - 0.026) * 100%, which simplifies to 0.1% = (0.000342 + 0.000088 + 0.000676) * 100% = 0.001106 * 100% = 0.11.

The contributions of NOS, pedagogy, and PPS to conceptual knowledge were found to be statistically insignificant, as indicated by $F (3, 84) = 0.031$, $p > .05$, with an overall contribution of 0.1%. Specifically, the contribution of PPS is 0.0676%. The adjusted R^2 value of -0.035 suggests that only 3.5% of the variance in conceptual knowledge can be explained by NOS, pedagogy, and PPS, which falls within the small range according to Cohen (1988). As per Cohen (1988), an adjusted R^2 value of 0.14 signifies a small effect, 0.36 represents a medium effect, and 0.51 represents a large effect and 0.71 or higher represents a much larger effect.

The established equation for the relationship is as follows: mean of conceptual knowledge = constant + (BNos factor * mean of NOS) + (B peda * mean of pedagogy) + (B PPS * mean of PPS). This translates to Y (CK) = 5.269 + (-0.004 * mean of NOS) + (-0.0044 * mean of pedagogy) + (-0.007 * mean of pps). Substituting the actual values, Y = 5.269 + (-0.004 * 56.1477) + (-0.0044 * 0.6364) + (-0.007 * 28.4205), resulting in 4.8636 = 5.269-0.2245908-0.0016016- 0.1989435 = 4.8425469. From the equation, it is evident that NOS, PPS, and pedagogy have negative impact on conceptual knowledge.

Effects of NOS, PPS, and Pedagogies on Procedural Knowledge

The results presented in **Table 4** show that the individual effects of NOS, pedagogy, and PPS on procedural knowledge are not statistically significant (NOS: p = 0.842, pedagogy: p = 0.635, PPS: p = 0.881). However, when considering the relative effects, NOS had the largest impact (partial eta-squared) (0.815 or

Table 4. Effects of NOS, pedagogy, and PPS on procedural knowledge

Source	Type III sum of squares	df	Mean square	F	p	Partial eta-squared
Corrected model	256.596[a]	84	3.055	.606	.816	.944
Intercept	.220	1	.220	.044	.848	.014
GPA	1.973	1	1.973	.391	.576	.115
Pedagogical orientation	1.826	1	1.826	.362	.590	.108
NOS	66.756	25	2.670	.530	.842	.815
PPS	56.092	24	2.337	.464	.881	.788
Pedagogy	1.401	1	1.401	.278	.635	.085
NOS * PPS	16.453	11	1.496	.297	.942	.521
NOS * pedagogy	.330	1	.330	.065	.815	.021
PPS * pedagogy	.000	0	.	.	.	.000
NOS * PPS * pedagogy	.000	0	.	.	.	.000
Error	15.120	3	5.040			
Total	3,239.000	88				
Corrected total	271.716	87				

Table 5. Regression for procedural knowledge as function of NOS, pedagogy, and PPS

Analysis of variance

Model		Sum of squares	df	Mean square	F	p
1	Regression	5.399	3	1.800	.568	.638[b]
	Residual	266.317	84	3.170		
	Total	271.716	87			

Variables in the equation

Model		Mean	Unstandardized coefficients		Standardized coefficients	T	p	r
			B	Standard error	Beta			
1	(Constant)		4.031	1.509		2.671	.009	
	CK	5.8068						1.00
	NOS	56.1477	.018	.023	.083	.767	.445	.088
	Pedagogy	.6364	-.059	.397	-.016	-.149	.882	-.002
	PPS	28.4205	.028	.028	.110	1.015	.313	.113

81.5%), followed by PPS (0.788 or 78.8%), with pedagogy showing a smaller effect (0.085 or 8.5%). The interaction effects of NOS*PPS (p = 0.942) and NOS*pedagogy (p = 0.815) were also found to be not significant. The partial eta-squared values for these interaction effects were 0.521 (52.1%) for NOS*PPS and 0.021 (2.1%) for NOS*pedagogy. Additionally, the interaction effects of PPS*pedagogy and NOS*PPS*pedagogy were found to be negligible.

The adjusted R^2 value was -0.015. The covariates appearing in the model are evaluated at the following values: GPA = 2.6469, pedagogical orientation = 16.4205 with the mean of dependent variable of procedural knowledge 5.8068.

To measure the effect of independent variables on the mean of the dependent variable (procedural knowledge), a multiple regression analysis was conducted. **Table 5** illustrates the regression for procedural knowledge about NOS, pedagogy, and PPS.

The combined impact of NOS, pedagogy, and PPS on procedural knowledge resulted in an R R^2 value of 0.020, with an adjusted R^2 value of -0.015. The equation used to represent this relationship is R^2 × 100% = (Bnos*rnos + Bpeda*rpeda + Bpps*rpps) x 100%. $R^2 \times 100\% = (B_{nos} * r_{nos} + B_{peda} * r_{peda} + B_{pps} * r_{pps}) \times 100\%$ + 0.020 × 100% = (0.083 × -0.088 + 0.016 × 0.002 + 0.11 × 0.113) × 100% = (0.007304 + 0.000032 + 0.01243) 100% = 0.019766 × 100% = 1.9766 = 2.00.

The contributions of NOS, pedagogies, and PPS on procedural knowledge is not statistically significant F (3, 84) = 0.568, p > .05, and the overall contribution is 2.0%. Out of this, the contribution of PPS is 1.2%. The adjusted R^2 value was -0.015. This indicates 1.5% of the variance in conceptual knowledge explained by NOS, pedagogies, and PPS. According to Cohen (1988), it is in a small range. When the mean values are plugged into the equation, it results in 5.8068 with pedagogy showing a negative impact and NOS demonstrating a greater positive impact on procedural knowledge. The relationship between the mean of procedural knowledge and the factors can be represented by the equation:

Y (PK) = 4.031 + (0.018*mean of NOS) + (-0.059*mean of pedagogies) + (0.028*mean of pps). Y (PK) = 4.031 + (0.018*mean of NOS) + (-.0.059*mean of pedagogies) + (0.028*mean of pps). Y = 4.031 + 0.018*56.1477) + (-0.059*0.6364) + (0.028*28.4205). 5.8068 = 4.031 + 1.0106586 - 0.0375476 + 0.795774 = 5.799885. From the equation, it is evident that NOS and PPS have positive impact, but pedagogy has a negative impact on procedural knowledge.

Table 6. Effects of NOS, pedagogy, and PPS on motivation

Source	Type III sum of squares	df	Mean square	F	p	Partial eta-squared
Corrected model	776.209	84	9.241	.339	.963	.905
Intercept	59.408	1	59.408	2.177	.237	.421
GPA	1.723	1	1.723	.063	.818	.021
Pedagogical orientation	1.795	1	1.795	.066	.814	.021
NOS	157.486	25	6.299	.231	.986	.658
PPS	214.630	24	8.943	.328	.952	.724
Pedagogy	3.075	1	3.075	.113	.759	.036
NOS * PPS	90.202	11	8.200	.300	.940	.524
NOS * pedagogy	.054	1	.054	.002	.967	.001
PPS * pedagogy	.000	0	.	.	.	.000
NOS * PPS * pedagogy	.000	0	.	.	.	.000
Error	81.870	3	27.290			
Total	60,815.000	88				
Corrected total	858.080	87				

Table 7. Regression for motivation as function of NOS, pedagogy, and PPS

Analysis of variance

Model		Sum of squares	df	Mean square	F	p
1	Regression	89.471	3	29.824	3.259	.026b
	Residual	768.609	84	9.150		
	Total	858.080	87			

Variables in the equation

Model		Mean	Unstandardized coefficients		Standardized coefficients	T	p	r
			B	Standard error	Beta			
1	(Constant)		25.444	2.564		9.923	.000	
	CK	26.1023						
	NOS	56.1477	-.005	.040	-.014	-.133	.895	-.019
	Pedagogy	.6364	-1.894	.674	-.292	-2.812	.006	-.278
	PPS	28.4205	.076	.048	.165	1.593	.115	.139

Effects of NOS, PPS, and Pedagogies on Motivation

In **Table 6**, the study presents the impact of NOS, pedagogy, and PPS on motivation. The results show that the individual effects of NOS ($p = 0.986$), pedagogy ($p = 0.759$), and PPS ($p = 0.952$) on motivation are not statistically significant. However, the effect sizes (partial eta-squared) are 0.658 (65.8%) for NOS, 0.724 (72.4%) for PPS, and 0.036 (3.6%) for pedagogy. Among these, PPS has a substantial effect, while NOS and pedagogy has relatively smaller effects. Furthermore, the interaction effects of NOS*PPS ($p = 0.94$) and NOS*pedagogy ($p = 0.967$) are also not statistically significant. However, the partial eta-squared for NOS*PPS is 0.524 (52.4%), and for NOS*pedagogy, it is 0.001 (0.1%). Additionally, the interaction effects of PPS*pedagogy and NOS*PPS*pedagogy are negligible.

To assess the influence of independent variables on the mean of the dependent variable (motivation), we utilized multiple regression analysis. **Table 7** illustrates the regression for motivation in relation to NOS, pedagogy, and PPS. The $R^2 = 0 .104$ (adjusted $R^2 = 0.072$). The covariates appearing in the model are evaluated at the following values: GPA = 2.6469, pedagogical orientation = 16.4205 with the mean of dependent variable of motivation 26.152.

$R^2 \times 100\% = (Bnos*rnos + Bpeda*rpeda + Bpps*rpps) \times 100\% = 0.104 \times 100\% = (-0.014 \times -0.019 - 0.292 \times -0.278 + 0.165 \times 0.139) \times 100\% = 10.40 = (0.000266 + 0.081176 + 0.022935) \times 100\% = 0.104377 \times 100\% = 10.427$.

The combined impact of NOS, pedagogy, and PPS on motivation resulted in an R^2 value of 0.104, with an adjusted R^2 of 0.072. The overall contributions of NOS, pedagogy, and PPS on motivation are statistically significant, with an F value of $(3, 84) = 3.259$, $p = 0.026 < 0.05$, and an overall contribution of 10.40%. Specifically, the contribution of pedagogy is 8.11%. The adjusted R square value of 0.072 indicates that 7.2% of the variance in motivation is explained by NOS, pedagogy, and PPS, falling within the small range according to Cohen (1988).

To assess the influence of independent variables on the mean of the dependent variable (motivation), we utilized multiple regression analysis. **Table 7** illustrates the regression for motivation in relation to NOS, pedagogy, and PPS.

The derived equation to model the relationship is: mean of motivation = constant + (Bnos factor * mean of NOS) + (B peda * mean of pedagogy) + (B pps * mean of PPS). This results in the equation Y (mot) = 25.444 + (-0.005 * mean of NOS) + (-1.894 * mean of pedagogy) + (0.076 * mean of PPS). After substitution, we get 26.1023

= 25.444 - 0.2807385 - 1.2053416 + 2.14358 = 26.09760734. From the equation, it is evident that pedagogy and NOS have a negative impact on motivation, while PPS has a notably positive impact.

DISCUSSION

The research employed a quasi-experimental method within a tandem design phase (III) to measure the independent and interaction effects of integrated components of three-paired match treatment groups. An association and/or correlation of independent and dependent variable with control of some selected covariates was conducted. The results from the ANCOVA test for independent and interaction effect analysis revealed that, when controlling for covariates such as overall academic performance and pedagogical orientation, there are no statistically significant effects of individual independent variables effects of NOS, PS, and pedagogies on dependent variables such as conceptual and procedural knowledge, and motivation. In addition, there were no statistically significant interaction effects of NOS, PS, and pedagogies on the dependent variables. However, partial eta-squared value indicated that there is relative remarkable individual and combined/interaction effect/contribution of each independent variable on dependent variables. In addition, the multiple regression indicated there is some effects of independent variables on dependent variables, in case of motivation that the overall association of independent variable has significant. Though there are multiple study worked in science/physics laboratory context, most of them focused on implementation of some selected forms of laboratories such as structured vs semi-structured, and uncontrolled and comparing their independent impact on students' learning outcomes of factual, conceptual, and procedural knowledge, views of NOS and PS, and motivation (Holmes et al., 2017; Kalman et al., 2018; Ramarian, 2016). In addition, some focused on implementation of pedagogies such as conventional vs guided-discovery, and free discovery and measure their impacts on students' factual, conceptual, and procedural knowledge, understanding or views of NOS, and motivation (Badri & Shri, 2013; Baloyi et al., 2017). The implicit or explicit approach of NOS and PS is mostly implemented area in science laboratory and debatable area in science education in terms of their effectiveness in conceptual and procedural knowledge, and motivation (Kalman et al., 2018). The study about PPS indicates a positive impact on students' conceptual knowledge (Schamann, 1993) with less clear way of presenting method of implementation and integration with other components. In addition, Baloyi et al. (2017) indicated that the instruction assisted NOS and PS had positive impact on students understanding of concepts in physics, but with less clear way of presenting forms of laboratory, contents and other assessment methods. Furthermore, a study aimed at comparing students' understanding of concepts between classes using the guided discovery learning model and the non-guided discovery model demonstrated notable differences in the improvement of concept understanding between the two groups (Syukri, 2020). While there is limited research demonstrating the influence of NOS on conceptual knowledge with the same implementation design as this study; however, some sources suggest that a comprehensive understanding of NOS contributes favorably to students' grasp of scientific knowledge (Lederman et al., 2013). An intervention study investigating the effects of SPS on conceptual knowledge found a significant (Sakinah & Yerimadesi, 2022). Moreover, the literature indicates that the acquisition of SPS also significantly influences the development of mental processes such as higher-order critical thinking and decision-making (Lee, 1978). However, in all previous studies the way of selecting and integrating the NOS, PS, pedagogy, and knowledge construction model not well stated. These hinders this study findings less statistically significant effects of NOS,PPS, and pedagogies on students achievement and motivation as other previous study findings. Even there is implication of effect analysis of eta-squared as there is impacts of each independent variables in individually and in interaction. Some previous studies revealed that integrating NOS and SPS on students learning have a significant effect on students' procedural knowledge including control group data (Daniel et al., 2021; Scharmann, 1994). Although there is a shortage of research demonstrating the impact of NOS on procedural knowledge, certain sources indicate that a thorough understanding of NOS contributes positively to students' procedural knowledge (Lederman et al., 2013). Furthermore, it was found that SPS promote students procedural knowledge (Daniel et al., 2021). Furthermore, the result indicates that the interaction effect of NOS, SPS, and pedagogy is also not significant on procedural knowledge. But, in all cases their eta-squared values indicates as there is contribution on all dependent variables.

Previous studies have shown that the guided discovery method has a positive impact on students' learning motivation (Fauzi & Respati, 2021; Rahmawati et al., 2020). According to these studies, the various steps and activities involved in the guided discovery method enable students to challenge themselves to discover new knowledge, may this study tools not measured. Additionally, it has been found that SPS enhance students' attitudes towards science, as the overall regression analysis indicated. Zeidan and Jayosi (2015) stated that SPS serves as a driving force for the growth and development of positive attitudes and values of science in students, while also increasing interest and motivation in students to learn science, which is also in agreement with the current study. The lack of a connection between science motivation and NOS views in a correlation study of middle school students differs from the findings of this study. This difference might be because the previous studies were not analyzed the integration effects of NOS, PPS, and pedagogies by integrating them in one framework, rather than independently studying each component separately. As well, they were conducted in schools and different college disciplines. Previous studies conducted on students that may not have had enough exposure to understand the fundamental aspects of NOS (Wicaksono et al., 2018).

While prior studies lack clear explanations of how NOS and SPS were pedagogically integrated with laboratory forms, this study uniquely employs implicit NOS implementation alongside explicit SPS training. We combined three guided-discovery methods with three laboratory formats (controlled, semi-structured, open) to facilitate differentiated discovery activities (Daniel et al., 2023a), assessed via pen-and-paper instruments with rated scales. Conducted in physics laboratories with third-year college students in formal classrooms, the study's distinctive design complicates direct comparisons of effectiveness with existing literature. However, the non-significant NOS/SPS effects observed may reflect Ethiopia's complex science education landscape. Historical infusions of French, British, American, and Russian/German approaches have created disjointed laboratory implementations lacking stable frameworks (Tesfaye, 2010). Systemic barriers include: cookbook-style lab manuals dominated by traditional methods (Daniel et al., 2021; Shimeles, 2010); Only 3.6%curricular emphasis on subject-specific pedagogy (Ministry of Education, 2009); Ambiguous standards for selecting/integrating core science education components (Areaya, 2008).

These align with cross-cultural evidence showing that implicit/explicit NOS/SPS approaches coupled with discovery pedagogy–without structured meta-cognitive tasks–often yield minimal gains (Lederman, 2007; Daniel et al., 2023a). Performance assessments in comparable contexts (Daniel et al., 2023a) suggest traditional evaluations (e.g., pen-and-paper tests) may obscure procedural/epistemic learning, potentially explaining our null results. To address these gaps, we propose: Integrated labs pairing hands-on tasks (e.g., circuit experiments) with guided NOS/PPS approaches (e.g., explicit SPS + implicit NOS) and scaffolded reflections (e.g., *"how might cultural perspectives influence data interpretation?"*); joint NOS-SPS rubrics (e.g., scoring "hypothesis formation" for testability *and* tentativeness acknowledgment); localized templates replacing cookbook procedures with open-ended guides (e.g., *"design a method to test Kirchhoff's Law using available materials"*). These align with Ethiopia's concurrent training model (Shishigu et al., 2017) by embedding pedagogy within content. We further recommend instructors adopt: explicit NOS bridging (e.g., linking lab conclusions to Feyerabend's "no single method" tenet); performance-based evaluations (e.g., video logs, lab report analyses) to track procedural growth. Such reforms could mitigate historical fragmentation while respecting resource constraints.

To sum up, the study's overall findings suggest that the implicit integration of NOS, the explicit approach of PS, and different forms of laboratories in integration/ combined with modified guided discovery methods, show less statistically significant independent and combined effects on students' conceptual and procedural knowledge, and motivation. However, the relative effect partial eta value and multiple regression analysis indicated that there is some influence of independent variables (NOS, PPS, and modified guided discovery models) on dependent variables. In addition, the study result under the same project including control group data indicates that, different implemented pedagogues, NOS and PPS had more of indirect effect on conceptual knowledge than direct. Moreover, the effect of different implemented pedagogues, NOS and PPS had more of direct effect on procedural knowledge than indirect effect, and the effect of PPS had more of direct effect on motivation, and NOS and implemented pedagogues had more of indirect effect on motivation (Daniel et al., 2021).

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APPENDIX A

Table A1. Alternative models of learning in terms of pedagogies, forms of lab, NOS, PS, and contents in physics laboratory (Daniel et al., 2023a)

Model of learning	Pedagogies used in physics lab	Forms of laboratory fit for the pedagogy	Presentation of contents, NOS, and PS	Presentation of question and answer for the question
Model 1. Knowledge can be acquired/confirmed by using structured contents and controlled form of lab.	Traditional/conventional method	Structured with detail steps in lab manuals, and set equipment for an experiment	Explicit content and PS using lecture/ demonstration, and implicit activity-based approach of NOS	Teacher pose questions, but in advance answers known
Model-2. Knowledge can be acquired and/ or an alternative knowledge constructed by using structured content and uncontrolled form of lab.	Structured guided-discover (SGD)	Open, however guidelines to set apparatus/ experiment in diagram	Concept injection (highlight/ lecture), explicit PS by lecture, and implicit activity-based approach of NOS	Teacher pose problem and answer questions based on data from the lab work and injected concepts
Model-3. Knowledge can be acquired and/ or an alternative knowledge can be constructed by using semi-structured curricula and structured/controlled form of lab.	Semi-structured guided-discovery (SSGD)	Structured (demonstrate how to set up lab materials)	Concept injection by demonstration, explicit PS by lecture, and implicit activity-based approach of NOS	Teacher pose problem, and answer the questions based on data from the lab work and demonstrated concepts
Model-4. Knowledge can be acquired and/ or an alternative knowledge can be constructed by using semi-structured content and semi-structured form of lab.	Scaffolding guided-discovery (SCGD)	Semi-structured, however guidelines, diagram, and lab setup given based on students request	Posing questions, explicit PS by and implicit activity-based approach of NOS	Teacher pose problem, and answer the questions based on data from the lab work, concepts injected
Model-5. An alternative knowledge can be constructed by using open contents and open form of lab.	Free discovery	Open, however close follow up how to use apparatus	Posing questions related to contents, explicit or implicit PS & NOS	Teacher pose problem, and answer the questions based on data from the lab