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Development and evaluation of science laboratory instructional model (AFGLIM) anchored on flipped classroom and guided inquiry approach for pre-service science teachers

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ABSTRACT

Laboratory instruction is central to science teacher preparation because it connects conceptual knowledge with scientific inquiry, practical competence, and the pedagogical skills required for future teaching. This study developed and evaluated the A Flipped-Guided Laboratory Instructional Model (AFGLIM) as a context-responsive framework for improving chemistry laboratory instruction among pre-service science teachers. A sequential exploratory mixed-method design was employed. Interviews, focus group discussions, and classroom observations involving laboratory teachers and pre-service science teachers informed the model's development, while the quantitative phase involved 80 first-year BSEd Science students across three campuses using a single-group pretest–posttest design. Conceptual understanding, laboratory skills, and science motivation were assessed using the Chemistry Concept Inventory (CCI), Integrated Science Process Skills Scale (ISPSS), and Science Motivation Questionnaire II (SMQ-II), respectively. Findings revealed adaptive and inquiry-oriented teaching practices alongside persistent constraints involving resources, time, student preparedness, professional development, and institutional support. Following AFGLIM implementation, conceptual understanding improved significantly (t = 2.96, p = 0.004), as did laboratory skills (t = 17.063, p < 0.001); the proportion of students classified as Highly Motivated increased from 9.2% to 79.3%. Expert validation progressively refined AFGLIM into a cyclical framework integrating flipped pre-laboratory preparation, guided inquiry, post-laboratory reflection and assessment, iterative feedback, and professional growth. The findings support AFGLIM as a promising framework for integrating conceptual, practical, affective, and professional dimensions of laboratory learning, while further comparative research is needed to establish its broader effectiveness and transferability.

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INTRODUCTION

Science laboratory instruction is a central component of science education, particularly in chemistry, where experimentation provides an important bridge between theoretical knowledge and observable phenomena. Well-designed laboratory experiences can promote conceptual understanding, scientific inquiry, problem-solving, and higher-order thinking by enabling students to engage directly with scientific processes rather than encounter them only as abstract concepts (Domin, 1999; Hofstein and Lunetta, 2004). Laboratory instruction also provides opportunities for students to develop essential scientific competencies through observation, experimentation, interpretation, and evidence-based reasoning. For pre-service science teachers, these experiences have an additional significance: laboratory courses contribute not only to their understanding of science but also to the development of the pedagogical and practical competencies they will eventually need as classroom teachers.

Despite this potential, meaningful laboratory learning is not always realized in practice. Laboratory instruction is frequently constrained by limited resources, large classes, restricted instructional time, and dependence on highly structured "cookbook" activities in which students follow predetermined procedures with limited opportunity to formulate questions, make decisions, or interpret evidence independently (Handelsman, 2004; Hofstein *et al.*, 2005). Under such conditions, completion of an experiment may become the primary objective, while the reasoning processes that make laboratory work educationally valuable receive less attention. These difficulties are particularly relevant in contexts where institutional and material constraints limit instructors' capacity to implement more learner-centered approaches. In the Philippine higher education context, limited access to professional development in laboratory pedagogy may further reinforce procedural and teacher-centered practices. Such conditions can restrict opportunities for pre-service science teachers to develop scientific reasoning, independent inquiry, and confidence in laboratory-based learning (Hofstein and Lunetta, 2004).

Two approaches are particularly relevant to addressing these instructional limitations: the flipped classroom and guided inquiry. In a flipped classroom, foundational content is introduced before face-to-face instruction through readings, recorded materials, simulations, or other digital resources, allowing scheduled laboratory time to be devoted more fully to experimentation, discussion, and cognitively demanding activities. In chemistry laboratory education, flipped learning can therefore shift part of the preparatory burden outside the laboratory and create more time for active engagement. Seery (2015) similarly describes the value of flipped and blended approaches in creating a more dynamic chemistry laboratory environment. Guided inquiry complements this structure by moving students beyond rigid procedural execution and providing opportunities to formulate hypotheses, make experimental decisions, analyze evidence, and construct explanations with appropriate instructional guidance (Hofstein and Lunetta, 2004). Rather than removing teacher support, guided inquiry repositions the instructor as a facilitator who provides sufficient scaffolding while allowing students greater intellectual responsibility for the investigation.

The educational rationale for integrating these approaches is consistent with constructivist perspectives on learning. Constructivism emphasizes that meaningful understanding develops as learners actively engage with experiences and relate new information to existing knowledge (Piaget, as cited in Muijs and Reynolds, 2011). This orientation is particularly applicable to laboratory learning, where students encounter phenomena, manipulate variables, interpret observations, and revise explanations through experience. Shulman's concept of Pedagogical Content Knowledge (PCK) provides a complementary perspective by emphasizing that effective teaching requires more than disciplinary knowledge; teachers must also understand how particular content can be represented, organized, and taught in ways that make it accessible to learners. For pre-service science teachers, laboratory instruction therefore represents an important setting in which disciplinary understanding, inquiry competence, and pedagogical preparation can develop together.

Modeling practices provide an additional foundation for this form of science learning because scientific models allow learners to describe, explain, communicate, and predict phenomena. Oh and Oh (2011) identify several practices associated with scientific modeling, including describing, explaining, predicting, communicating, designing, evaluating, revising, comparing, and selecting models. Engagement with modeling can support increasingly sophisticated understandings of how models function in scientific reasoning and knowledge construction (Krell and Krüger, 2016). Students may progress from viewing models primarily as representations toward using them as tools for reasoning and scientific investigation (Hodson, 2014; Justi and Van Driel, 2005). Teachers' knowledge of models and modeling is equally important because their instructional decisions influence students' opportunities to develop modeling competence (Van Driel and Verloop, 1999). These perspectives reinforce the need for laboratory environments that require students to reason with evidence rather than merely reproduce predetermined experimental procedures.

The flipped classroom and guided inquiry are consequently complementary rather than competing instructional approaches. Flipped preparation can provide students with the conceptual background needed before entering the laboratory, while guided inquiry can use laboratory time for questioning, experimentation, analysis, collaboration, and reflection. The flipped classroom has been discussed as a means of shifting preparatory learning outside scheduled class time so that students can engage more actively during laboratory sessions (Seery, 2015). Guided inquiry, meanwhile, encourages learners to investigate scientific questions while instructors provide structured guidance appropriate to students' level of experience (Hofstein and Lunetta, 2004). Their integration is particularly relevant to chemistry topics such as equilibrium, kinetics, and stoichiometry, where students need conceptual preparation before they can meaningfully interpret experimental observations. Together, the two approaches provide a pedagogical basis for connecting pre-laboratory preparation with active inquiry during laboratory work and subsequent reflection.

The effectiveness of such approaches nevertheless depends on the broader instructional environment in which they are implemented. Science teachers are expected to facilitate learning, support students' participation in scientific investigation, and help learners connect conceptual knowledge with practical experience (Hançer *et al.*, 2003). Laboratory activities can promote active participation (Patel and Smith, 2021), connect theory with practical application (Cullin, Hailu, Kupilik, and Petersen, 2017), and contribute to more meaningful understanding of scientific concepts. Laboratories have therefore remained an important component of science teaching and learning (Kwok, 2015), particularly when experimental activities are designed to address misconceptions and strengthen conceptual understanding. Direct engagement in experimental work can also provide experiences through which students develop a deeper understanding of scientific principles (Lee and Kim, 2017).

However, the literature and contextual problems identified above reveal an important research and practice gap. Existing scholarship provides substantial support for laboratory learning, flipped instruction, guided inquiry, constructivist learning, and pedagogical content knowledge as individual or related educational perspectives. What remains insufficiently addressed in the context examined in this study is how these elements can be brought together within a coherent, context-responsive laboratory instructional model for pre-service science teachers that begins with preparation before the laboratory, structures inquiry during experimentation, incorporates formative feedback and post-laboratory reflection, and extends laboratory learning toward professional preparation. Equally important, an instructional model intended for this context must respond to actual teaching and laboratory-management conditions rather than being developed solely from theoretical assumptions. The need is therefore not simply for another isolated teaching strategy, but for an integrated framework grounded simultaneously in established pedagogical principles and empirical evidence from the laboratory environments in which it will be used.

To address this gap, the present study developed the Anchored Flipped and Guided Laboratory Instructional Model (AFGLIM) by integrating flipped classroom and guided inquiry approaches with evidence obtained from chemistry laboratory instructors and pre-service science teachers. Interviews, focus group discussions, and classroom observations were used to examine how laboratory sessions were prepared, delivered, supervised, and managed, thereby providing an empirical basis for identifying instructional needs and determining the components required in the model. AFGLIM consequently brings together contextualized pre-laboratory preparation, guided in-laboratory activities, formative checkpoints, post-laboratory feedback and reflection, and professional growth integration. In this formulation, laboratory instruction is treated as a connected learning process extending from preparation through experimentation and reflection to the development of competencies relevant to future science teaching.

The conceptual relationships underlying the study are presented in Fig. 1. The framework positions Piaget's constructivist perspective and Shulman's Pedagogical Content Knowledge as complementary theoretical foundations for the integration of flipped classroom and guided inquiry approaches. These foundations inform the development of AFGLIM by linking active knowledge construction with the pedagogical knowledge required to organize meaningful laboratory learning. Accordingly, the framework provides the conceptual basis for examining how an integrated laboratory instructional model may support the conceptual understanding, laboratory skills, motivation, and professional preparation of pre-service science teachers.

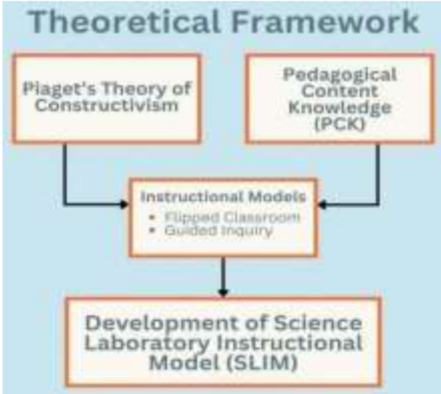

Fig. 1. Theoretical framework for the development of science laboratory instructional model anchored on flipped classroom and guided inquiry approach for pre-service science teachers

Against this background, the study aimed to develop and evaluate AFGLIM as a context-responsive instructional model for chemistry laboratory education among pre-service science teachers. Specifically, it sought to (1) examine the teaching practices of laboratory teachers in terms of pedagogical effectiveness and laboratory management; (2) determine the extent to which pre-service science teachers attain conceptual understanding, laboratory skills, and motivation toward science; and (3) develop AFGLIM as an instructional model grounded in the identified instructional needs and the principles of flipped classroom and guided inquiry.

MATERIALS AND METHODS

Research design

This study employed a sequential exploratory mixed-methods design (QUAL → quan) to develop and evaluate the Anchored Flipped and Guided Laboratory Instructional Model (AFGLIM) for pre-service science teachers. The qualitative phase served as the exploratory and needs-analysis stage, while the subsequent quantitative phase examined changes in student learning outcomes following implementation of the developed model. This sequencing allowed evidence from existing laboratory practices and participant experiences to inform model construction before its classroom evaluation. The quantitative component followed a single-group pretest–posttest design; therefore, the observed changes were interpreted as within-group differences following the intervention rather than definitive causal effects attributable exclusively to AFGLIM.

Research setting and participants

The study was conducted at a state university in Zamboanga del Norte, Philippines, which operates five campuses located in Dapitan, Dipolog, Katipunan, Tampilisan, and Siocon. General Chemistry laboratory classes within the Bachelor of Secondary Education (BSEd) Science program provided the instructional context. The qualitative phase involved 25 chemistry instructors and pre-service science teachers, who participated through interviews, focus group discussions, and classroom observations. The quantitative phase involved 80 first-year BSEd Science students from three campuses. The manuscript does not specify the sampling technique, participant distribution within the qualitative sample, or detailed eligibility criteria; these should be provided by the authors in the final version rather than inferred.

Qualitative needs analysis and development of AFGLIM

Before developing AFGLIM, qualitative data were collected to characterize existing laboratory teaching practices and identify pedagogical and laboratory-management challenges. Interviews, focus group discussions, and classroom observations explored instructional practices, guided-inquiry and flipped-learning strategies, student engagement, and areas requiring improvement. Interview and focus-group data were transcribed and thematically analyzed following Braun and Clarke (2006), with MAXQDA used to facilitate coding and data organization. Peer debriefing, member checking, and triangulation with classroom observations were employed to strengthen the credibility of the qualitative interpretation. The resulting evidence informed the development and refinement of AFGLIM. The manuscript further reports that the researcher-developed Laboratory Assessment Tool for Science Educators underwent face and content validation by seven science educators and experts, together with pilot testing to improve clarity and content relevance.

Quantitative implementation and research instruments

Following model development and refinement, AFGLIM was implemented with the 80 first-year BSEd Science students using a single-group pretest–posttest design. The model integrated flipped pre-laboratory preparation, guided inquiry during laboratory activities, formative assessment, feedback, reflection, and professional-growth activities. Student outcomes were assessed using the Chemical Concepts Inventory (CCI), an integrated science process skills measure reported in the manuscript as ISPSS, the Science Motivation Questionnaire II (SMQ-II), and technology-integration self-assessment measures. The established CCI was developed by Mulford and Robinson (2002) to assess alternative conceptions in introductory chemistry, while the SMQ-II developed by Glynn *et al.* (2011) measures five dimensions of science-learning motivation. The authors should identify the original source and exact version of the ISPSS and technology-integration instrument and report the number of items, scoring procedures, adaptations, and reliability estimates for all measures used.

Data analysis

Qualitative data were analyzed thematically, whereas quantitative data were analyzed using descriptive statistics, paired-samples *t*-tests, Wilcoxon signed-rank tests, and normalized gain (N-gain), as reported in the manuscript. The paired-samples *t*-test was used for appropriate paired pretest–posttest comparisons, while the Wilcoxon signed-rank test provided a non-parametric alternative where relevant. Integration occurred sequentially, with qualitative findings informing model development and quantitative evidence subsequently assessing changes in selected outcomes following implementation. For stronger methodological reproducibility, the final manuscript should report the statistical software and version, significance threshold, assumption checks, effect sizes and confidence intervals, handling of missing observations and outliers, and the specific outcome variables analyzed using each statistical procedure.

Ethical considerations

The study adhered to the ethical principles outlined in the Belmont Report (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). Informed consent and confidentiality were maintained throughout the study.

RESULTS AND DISCUSSION

SOP 1- Teaching practices of laboratory teachers

The analysis of laboratory teachers' practices revealed a pattern of pedagogical adaptation occurring within substantial contextual constraints. Four interrelated themes emerged from the interviews and focus group discussions: adaptive pedagogical practices, laboratory management and learning-environment conditions, persistent instructional and management challenges, and the need for institutional support and collaboration. As summarized in Fig. 2, these themes indicate that teachers were actively attempting to adopt student-centered and inquiry-oriented practices, although their capacity to sustain these approaches was shaped by resource availability, time, professional support, and institutional conditions.

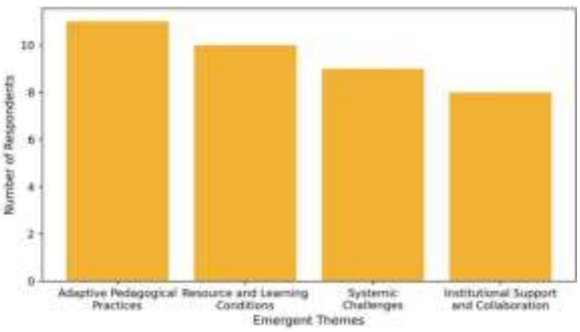

Fig. 2. Distribution of emergent themes from laboratory teachers' interviews (N = 20)

The first theme concerned adaptive teaching practices. Teachers described moving beyond exclusively teacher-directed laboratory instruction by incorporating pre-laboratory orientation, active learning, guided inquiry, and contextualized activities. Brief discussions before experimentation were used to establish the purpose of laboratory tasks, while readings and instructional videos were sometimes provided in advance. As one teacher explained, "I talk about the goal for a little bit before they do the experiment" (LT1), while another noted, "We give students videos and reading assignments to do before the session to make the most of their time in the lab" (LT2). These accounts suggest that teachers were already employing elements compatible with flipped learning, particularly by shifting some conceptual preparation outside the laboratory so that scheduled laboratory time could be used more productively for active experimentation.

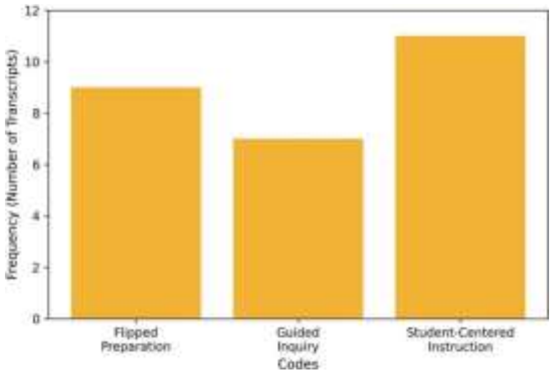

Fig. 3. Code frequency chart for adaptive pedagogical strategies (N = 20)

This pattern was prominent in the MAXQDA analysis, with 11 of the 20 participants referring to flexible and student-centered instructional strategies. Codes related to *Flipped Preparation*, *Guided Inquiry*, and *Student-Centered Instruction* frequently appeared together, as illustrated in Fig. 3. The quantitative evidence was consistent with these accounts: learner-centered classroom activities (M = 4.70) and active learning strategies (M = 4.65) were both rated as Very High Practice. The convergence of interview and quantitative evidence therefore suggests that active and inquiry-oriented teaching was not simply an expressed preference but an identifiable feature of instructional practice. This finding is consistent with evidence that active learning can improve student performance in STEM (Freeman *et al.*, 2014), while flipped preparation can create additional opportunities for meaningful engagement during class (Bergmann and Sams, 2012). Guided inquiry similarly provides opportunities to develop scientific reasoning and problem-solving rather than limiting laboratory work to procedural completion (Abrahams and Reiss, 2012).

A second theme concerned laboratory management and the learning environment. Teachers consistently emphasized advance preparation of materials, safety, supervision, and the need to adjust activities when time or resources were limited. Their comments illustrate a pragmatic form of laboratory management in which instructional decisions were continually adapted to available conditions. One teacher stated, "I get the materials ready ahead of time and remind people to be safe" (LT5), while another explained, "I walk around to help them while they do the activity" (LT3). Time pressure also affected instructional decisions: "Because I don't have much time, I cut down on activities and focus on the main goals" (LT4). These statements show that laboratory management was closely connected to pedagogy; decisions about resources, supervision, and time directly influenced what students were able to experience during an investigation.

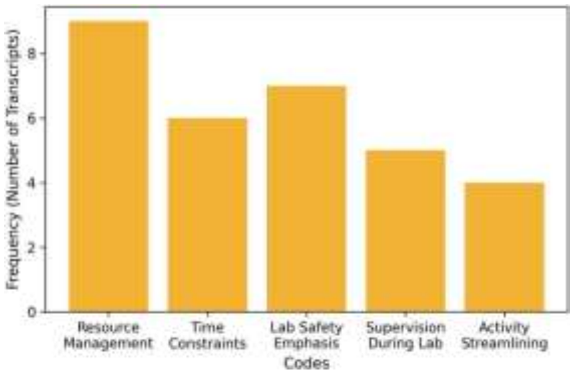

Fig. 4. Distribution of laboratory management–related codes across interview transcripts (N = 20)

The MAXQDA analysis identified laboratory management as the second most frequently discussed area, appearing in 10 of the 20 interviews. As shown in Fig. 4, codes such as *Resource Management*, *Time Constraints*, and *Lab Safety Emphasis* commonly co-occurred. Quantitative findings supported this interpretation: preparing and setting up equipment before laboratory sessions received a mean of 4.60, while close supervision during experiments received a mean of 4.25. At the same time, insufficient equipment and materials (M= 4.25) and limited laboratory time (M= 3.75) remained important constraints. Thus, effective management did not indicate an absence of difficulties; rather, teachers appeared to compensate for structural limitations through preparation, supervision, and adaptation.

The third theme captured persistent instructional and management challenges. Teachers identified shortages of chemicals, glassware, and other laboratory materials, together with restricted instructional time, outdated or inflexible curricula, and insufficient opportunities for continuing professional development. These constraints sometimes required laboratory activities to be simplified, modified, or omitted. One teacher explained, "Since we frequently lack chemicals and glassware, we are forced to make adjustments or improvise" (R6). Professional-development needs were equally apparent: "We require additional training as well as a lab guide that is structured" (R7), and "I wish we had more opportunities for training and collaboration" (R8). The findings indicate that teachers' willingness to use inquiry-oriented approaches was not always matched by the material and professional conditions required for consistent implementation.

The same constraints were visible from the learners' perspective. Pre-service science teachers described laboratory experiences as frequently procedural, with limited opportunities to question, explore, or reason independently. One participant observed, "Most of the time, we just follow the procedure. We don't really explore or ask questions." Another reported, "We rarely had pre-lab discussions, so sometimes we didn't understand the purpose of the experiment." Resource limitations also reduced direct participation: "There were too many students, so only a few handled the equipment while the rest watched." The convergence of teacher and student accounts is important because it shows how institutional constraints were translated into the actual learning experience—reducing opportunities for hands-on participation, inquiry, and conceptual engagement.

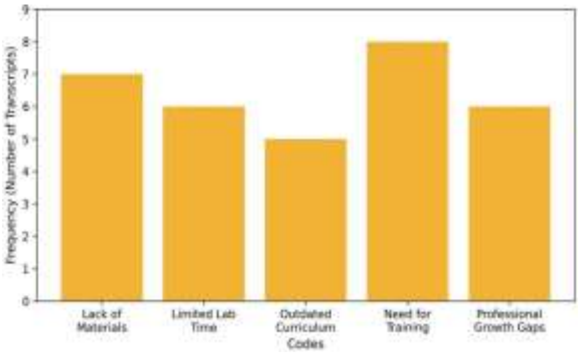

Fig. 5. Code frequency chart of systemic challenges in laboratory instruction (N = 20)

These concerns appeared in nine of the 20 interview transcripts, particularly through the codes *Lack of Materials*, *Need for Training*, *Outdated Curriculum*, and *Professional Growth Gaps*, as shown in Fig. 5. Survey findings reinforced the qualitative evidence: insufficient equipment and materials received the highest challenge rating (M= 4.25), followed by large class sizes and limited laboratory space (M= 3.80), time constraints (M= 3.75), and limited training or experience in laboratory management (M= 3.70). Similar constraints have been documented in science laboratory education, where limited resources may shift instruction away from hands-on investigation, while inadequate facilities, curricular limitations, and insufficient professional development can restrict inquiry-oriented teaching (Alake-Tuenter *et al.*, 2013). These findings therefore provide a contextual rationale for an instructional model that remains pedagogically ambitious while accounting for the realities of resource-constrained laboratory environments.

The fourth theme concerned institutional support and collaboration. Teachers regarded infrastructure, adequate materials, professional development, administrative responsiveness, and access to technology as conditions necessary for sustaining improvements in laboratory instruction. Their comments were direct: "Providing basic equipment and tools would help a lot" (R11), "We should have regular seminars and share what works best for us" (R9), and "Virtual simulations are useful when you can't use real tools" (R10). These accounts broaden the interpretation of laboratory effectiveness beyond individual teacher competence. Even teachers who are willing to adopt inquiry-based or technology-supported strategies require an institutional environment capable of supporting those practices.

This interpretation is consistent with previous research showing that inadequate infrastructure, outdated materials, and weak institutional implementation can constrain meaningful laboratory learning. The American Chemical Society (ACS, 2016) similarly emphasizes the importance of appropriate laboratory facilities, systematic risk management, safety education, and the development of a strong safety culture in academic laboratory environments. Teachers also identified professional learning as a continuing need, particularly training in guided inquiry, flipped learning, and technology-enhanced instruction. This concern corresponds with Baier-Mosch and Kunter (2024), while the participants' emphasis on mentoring, peer learning, and collaborative practice is consistent with literature on professional learning communities and instructional improvement. Administrative encouragement and policy support may further strengthen teachers' capacity to adopt innovative instructional practices.

Institutional support was among the most pervasive themes, appearing in 17 of the 20 transcripts (85%). Codes related to *Need for Training*, *Professional Collaboration*, *Virtual Alternatives*, *Resource Requests*, and *Institutional Support Needed* frequently clustered together, as shown in Fig. 6. The quantitative findings were consistent with this concern: institutional support and professional development produced an overall mean of 2.87, interpreted as Limited Support, although access to technology received a comparatively higher mean of 3.60. Taken together, the findings indicate that sustainable improvement in laboratory instruction depends on the interaction between teacher practice and institutional capacity. AFGLIM therefore needs to function not merely as a sequence of classroom activities but as an instructional model responsive to professional development, resource availability, collaboration, and institutional support.

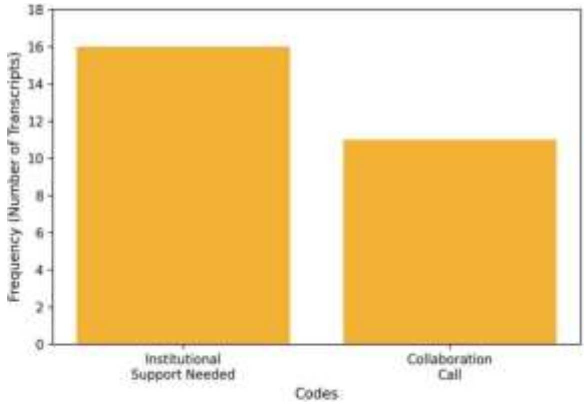

Fig. 6. Code frequency chart of institutional support and collaboration (N = 20)

Thematic analysis of pre-service science teachers (PSTs)

The accounts of pre-service science teachers provided a complementary view of laboratory instruction. Their first theme reflected a tension between traditional procedural instruction and emerging student-centered practices. Many PSTs described laboratory activities as highly prescribed, leaving little room for questioning or independent exploration. As one participant stated, "Most of the time we just follow steps. We don't really explore ideas or ask questions." Although some instructors incorporated active learning and flipped-classroom elements, students perceived these practices as inconsistent and constrained by large classes and limited instructional time. Their accounts suggest that introducing inquiry activities alone may be insufficient; students also require structured preparation, explicit learning goals, and appropriate scaffolding if laboratory work is to move from procedural completion toward scientific reasoning.

A second theme concerned resources and the laboratory learning environment. Students reported malfunctioning or incomplete equipment, limited consumables, overcrowding, and uneven opportunities to participate directly in experiments. One participant stated, "Sometimes the equipment is broken or incomplete, so we skip parts of the experiment," while another explained, "There are too many of us in one experiment, so only a few can actually do theactivity." These experiences reinforce the teachers' accounts and show that resource constraints have pedagogical consequences: when equipment is scarce or group sizes are too large, hands-on learning may become observational for some students rather than genuinely participatory. This finding supports the inclusion within AFGLIM of practical strategies for material preparation, group organization, safety, and time management.

The third theme concerned gaps across the laboratory learning cycle. Students described insufficient pre-laboratory orientation, limited opportunities for post-laboratory discussion, and laboratory periods that were too compressed for sustained inquiry and reflection. One participant explained, "We sometimes start the experiment without understanding the purpose." Such experiences suggest a disconnect between performing an experiment and understanding why it is being performed. The finding provides a clear rationale for AFGLIM's emphasis on pre-laboratory preparation, formative checkpoints, and post-laboratory reflection, which together are intended to connect conceptual preparation, experimental activity, and subsequent interpretation.

The fourth theme was the need for institutional and collaborative support. PSTs emphasized adequate laboratory infrastructure, current learning materials, digital resources, mentoring, and opportunities for collaborative practice. Technology was regarded as particularly useful where physical equipment was unavailable, as reflected in the statement, "Virtual simulations help a lot when equipment is unavailable." Students also valued structured mentoring and guided practice as preparation for their future professional responsibilities. These findings parallel the teachers' accounts and suggest that sustainable laboratory improvement requires support beyond individual lessons. They consequently informed the Professionalization and Institutional Support component of AFGLIM, linking laboratory learning with the broader preparation of future science educators.

Observed pedagogical effectiveness in laboratory instruction

External observations provided an independent perspective on the pedagogical practices identified through interviews and self-report. As presented in **Table 1**, the overall mean for observed pedagogical effectiveness was 4.35, interpreted as Highly Evident Practice. Particularly strong indicators were encouraging student inquiry and problem-solving (M= 4.50), connecting laboratory activities to real-life applications (M= 4.50), fostering collaboration and group learning (M= 4.40), and engaging students in hands-on, minds-on activities (M= 4.35).

Table 1. Observed pedagogical effectiveness by observer/external evaluator (N=20)

Statements	Mean	SD	Interpretation
1. Demonstrates clarity in explaining scientific concepts.	4.30	0.47	Highly Evident Practice
2. Encourages student inquiry and problem-solving.	4.50	0.60	Highly Evident Practice
3. Connects lab activities to real-life applications.	4.50	0.68	Highly Evident Practice
4. Utilizes a variety of teaching strategies (e.g., inquiry-based, flipped learning).	4.30	0.57	Highly Evident Practice
5. Engages students in hands-on, minds-on tasks.	4.35	0.58	Highly Evident Practice
6. Fosters collaboration and group learning.	4.40	0.59	Highly Evident Practice
7. Uses assessment tools (e.g., rubrics, reflective questions) to evaluate learning.	4.35	0.48	Highly Evident Practice
8. Integrates prior knowledge and scaffolds new learning.	4.20	0.95	Evident Practice
9. Provides timely and constructive feedback.	4.30	0.57	Highly Evident Practice
10. Aligns laboratory lessons with learning objectives and standards.	4.25	0.44	Highly Evident Practice
OPE Overall Mean	4.35	0.31	Highly Evident Practice
Cronbach's alpha	0.70	—	Acceptable reliability

Note. Scale interpretation: 1.00–1.80= Not Evident; 1.81–2.60= Slightly Evident; 2.61–3.40= Moderately Evident; 3.41–4.20= Evident Practice; 4.21–5.00= Highly Evident Practice.

These observations support the qualitative finding that inquiry, collaboration, and contextualization were visible features of laboratory teaching rather than merely stated preferences. Hofstein and Lunetta (2004) similarly emphasize that laboratory learning is strengthened when students actively explore phenomena through inquiry and collaboration. The strong rating for connecting experiments to real-life applications is also consistent with contextualized approaches intended to make scientific learning more meaningful and relevant (Prince and Felder, 2006). Thus, the observed practices align closely with the pedagogical principles underlying AFGLIM.

The comparatively lower rating for integrating prior knowledge and scaffolding new learning (M = 4.20, SD = 0.95) identifies an area requiring attention. Notably, according to the scale reported beneath Table 1, a mean of 4.20 falls within "Evident Practice," not "Highly Evident Practice." The relatively large SD also indicates greater variability across observed sessions. This distinction is educationally meaningful because effective scaffolding requires instructors to connect new experiences with learners' existing cognitive frameworks (Bransford *et al.*, 2000). Strengthening strategies such as advance organizers, formative questioning, and explicit activation of prior knowledge could therefore make inquiry-oriented laboratory instruction more consistent across instructors.

External evaluators looked at how laboratories are run

External evaluators also assessed laboratory management. As reported in **Table 2**, the overall mean was 4.27 (SD= 0.33), interpreted as Very High Practice. The strongest areas included maintaining a safe and efficient laboratory environment (M= 4.40), providing clear safety and equipment instructions (M= 4.40), supervising students during experiments (M= 4.35), and managing multiple groups or tasks simultaneously (M= 4.35). The scale showed acceptable internal consistency (Cronbach's α= 0.79).

Table 2. Observed Laboratory Management by observers (N=10)

Statements	Mean	SD	Interpretation
1. Prepares and organizes lab materials in advance.	4.10	0.55	High Practice
2. Maintains a safe, clean, and efficient laboratory environment.	4.40	0.59	Very High Practice
3. Gives clear instructions on safety and use of equipment.	4.40	0.59	Very High Practice
4. Supervises students attentively during experiments.	4.35	0.48	Very High Practice
5. Manages time efficiently across different stages of lab work.	4.10	0.64	High Practice
6. Adapts lab activities based on available resources.	4.25	0.63	Very High Practice
7. Ensures equitable access to laboratory tools and materials.	4.20	0.61	High Practice
8. Encourages student responsibility in equipment handling and clean-up.	4.30	0.57	Very High Practice
9. Manages large groups or multiple tasks simultaneously.	4.35	0.48	Very High Practice
10. Provides contingency plans when resources are insufficient or unavailable.	4.25	0.44	Very High Practice
OLM Overall Mean	4.27	0.33	Very High Practice
Cronbach's alpha	0.79	—	Acceptable Reliability

Note. Scale interpretation: 4.21–5.00= Very High; 3.41–4.20= High; 2.61–3.40= Moderate; 1.81–2.60= Low; 1.00–1.80= Very Low

Table 3. Teaching practices related to pedagogical challenges (N = 20)

Statements	Mean	SD	Interpretation
1. Difficulty fostering student engagement and participation.	3.15	0.67	Moderate Challenge
2. Students lack practical skills and inquiry experience.	3.35	0.48	Moderate Challenge
3. Difficulty in assessing problem-solving and critical thinking.	3.10	0.55	Moderate Challenge
4. Adapting activities to diverse learning styles and needs.	2.50	0.60	Slight Challenge
5. Difficulty aligning laboratory tasks with curriculum standards.	2.35	0.81	Slight Challenge
Overall Mean	2.89	0.42	Moderate Challenge
Cronbach's α	0.798	—	Acceptable Reliability

Note. Scale interpretation: 1.00–1.80= Not Serious; 1.81–2.60= Slight Challenge; 2.61–3.40= Moderate Challenge; 3.41–4.20= Serious Challenge; 4.21–5.00= Very Serious Challenge.

The high ratings for safety and supervision indicate that teachers were generally able to maintain the operational conditions necessary for hands-on laboratory work. This finding is consistent with the National Research Council (2006), which emphasizes effective supervision, appropriate management of laboratory activities, and the maintenance of laboratory safety as essential components of teachers' capacity to lead laboratory experiences. Teachers also demonstrated adaptability: modifying activities according to available resources and preparing contingency arrangements both received M= 4.25. Such flexibility is particularly important in contexts where material availability cannot always be assumed. Student responsibility for equipment handling and cleanup was also rated highly (M = 4.30), supporting Bybee's (2013) view that laboratory learning should foster responsibility and learner independence in addition to procedural competence.

Pre-laboratory preparation and time management received comparatively lower, although still high, ratings (M= 4.10). These areas are particularly relevant to AFGLIM because effective flipped and inquiry-oriented laboratory instruction depends on students entering the laboratory adequately prepared and on instructors allocating sufficient time for investigation, analysis, and reflection. Bergmann and Sams (2012) and Hung (2015) similarly emphasize the role of advance preparation in maximizing productive face-to-face learning time. The findings therefore suggest that laboratory management was generally strong, but that more systematic pre-laboratory planning and time allocation could further support inquiry-oriented instruction.

Pedagogical challenges in laboratory instruction

Despite generally strong observed pedagogical practices, teachers continued to experience meaningful instructional challenges. As presented in **Table 3**, the overall mean was 2.89 (SD= 0.42), corresponding to a Moderate Challenge, with acceptable internal consistency (Cronbach's α= 0.798). The most prominent difficulties were students' limited practical skills and inquiry experience (M= 3.35), fostering engagement and participation (M= 3.15), and assessing problem-solving and critical thinking (M= 3.10).

These findings reveal an important distinction between teachers' instructional practices and students' readiness to participate in inquiry. Teachers may employ learner-centered strategies while still encountering students who have had limited prior experience with open-ended investigation, scientific reasoning, or practical laboratory decision-making. This interpretation is consistent with Abrahams and Millar (2008), who showed that practical work does not necessarily lead to conceptual understanding when students concentrate primarily on completing procedures. Hofstein and Kind (2012) likewise emphasize the importance of meaningful inquiry experiences for developing students' scientific thinking. The results therefore support the use of progressive scaffolding within AFGLIM rather than assuming that students can immediately move from highly procedural laboratory work to independent inquiry.

Table 4. Laboratory management challenges

Statements	Mean	SD	Interpretation
1. Large class sizes and limited lab space.	3.80	0.52	Serious Challenge
2. Insufficient access.	4.25	0.63	Very Serious Challenge
3. Time constraints during lab periods.	3.75	0.38	Serious Challenge
4. Safety and risk management.	3.20	0.52	Moderate Challenge
5. Budget limitations.	4.00	0.64	Serious Challenge
6. Limited training or experience in lab management.	3.70	0.86	Serious Challenge
LMC Overall Mean	3.78	0.31	Serious Challenge
Cronbach's alpha	0.30	—	Poor Reliability

Note. Scale interpretation: 1.00–1.80 = Not a Challenge; 1.81–2.60 = Slight; 2.61–3.40 = Moderate; 3.41–4.20 = Serious; 4.21–5.00 = Very Serious.

Laboratory-management constraints were more pronounced. Table 4 reports an overall mean of 3.78, interpreted as a Serious Challenge. Insufficient access to equipment and materials was the most severe concern (M= 4.25), followed by budget limitations (M= 4.00), large class sizes and restricted laboratory space (M = 3.80), time constraints (M= 3.75), and limited training or experience in laboratory management (M= 3.70). Safety and risk management received a comparatively lower mean of 3.20 but remained a Moderate Challenge. These findings are consistent with research linking resource and institutional limitations with restricted opportunities for meaningful laboratory inquiry (Hofstein and Kind, 2012; Alake-Tuenter *et al.*, 2013).

Resource limitations were particularly consequential because they affected both what could be taught and how students could participate. As one teacher explained, "We often have to make things up or skip activities because we don't have the right materials." (R3). Large classes, limited laboratory space, and short laboratory periods similarly reduced opportunities for extended investigation, individualized guidance, and timely feedback. These findings underscore the importance of appropriate laboratory conditions and instructional support for meaningful practical learning (Hofstein and Lunetta, 2004) and reinforce the need for AFGLIM to accommodate realistic contextual constraints through advance planning, strategic grouping, contextualized resources, and carefully structured inquiry.

Limited training in laboratory management (M= 3.70) and budget constraints (M= 4.00) further demonstrate that instructional improvement cannot be achieved through pedagogical redesign alone. Continuous professional learning, mentoring, microteaching, and reflective practice are relevant responses to the reported competency needs, while persistent financial constraints affect equipment, consumables, maintenance, and the range of experiments that can realistically be offered. Safety and risk management, although rated less severely

(M= 3.20), also require continued attention because effective laboratory learning depends on proactive risk management as well as compliance with routine safety procedures.

SOP 2- Attainment of laboratory instruction goals

The quantitative findings indicate measurable improvement across the three outcomes examined: conceptual understanding, laboratory skills, and attitudes and motivation toward science. As summarized in Table 5, conceptual understanding measured through the Chemistry Concept Inventory (CCI) improved significantly (t= 2.96, p= 0.004), while laboratory skills measured through the Integrated Science Process Skills Scale (ISPSS) showed a substantial pretest–posttest difference (t= 17.063, p < 0.001). Motivation also shifted markedly, with the proportion of students classified as Highly Motivated on the Science Motivation Questionnaire II (SMQ-II) increasing from 9.2% to 79.3%.

The significant improvement in CCI scores suggests that students developed stronger conceptual understanding following the laboratory experience. This is particularly relevant in chemistry, where effective laboratory learning requires students to connect observable experimental phenomena with underlying scientific concepts rather than simply complete prescribed procedures. The result therefore suggests progress toward one of the central goals of AFGLIM: strengthening the connection between conceptual preparation and practical laboratory experience.

Table 5. Pre-service teachers demonstrated significant gains

Dimension	Instrument used	Result / Statistical evidence	Interpretation
Conceptual Understanding	Chemistry Conce pt Inventory (CCI)	t = 2.96, p = 0.004	Significant improvement in linking theory to practice
Laboratory Skills	Integrated Scienc e Process Skills S cale (ISPSS)	t = 17.063, p < 0.001	More students attained advanced laboratory skills
Attitudes & Motivation	Science Motivatio n Questionnaire II (SMQ-II)	9.2% → 79.3% Highly Motivated	Greater enthusiasm and confidence toward learning

The pronounced improvement in ISPSS scores indicates corresponding development in students' laboratory and science-process skills. The magnitude of the reported test statistic (t= 17.063, p < 0.001) indicates a clear difference between the paired measurements, although an effect-size estimate would be needed to establish the magnitude of that change independently of sample size. Conceptually, the improvement is consistent with the guided-inquiry component of AFGLIM, which provides opportunities for students to engage more actively in experimentation, problem-solving, data interpretation, and scientific reasoning rather than functioning solely as followers of predetermined procedures.

The motivational results complement these cognitive and practical outcomes. The increase in the Highly Motivated category from 9.2% to 79.3% indicates a substantial positive shift in students' disposition toward science learning. The manuscript associates this change with greater confidence, task enjoyment, self-efficacy, and perceived value of laboratory learning. Taken together, the CCI, ISPSS, and SMQ-II findings suggest that attainment extended across both cognitive and affective domains. This pattern is consistent with Aidoo *et al.* (2022), who reported benefits of flipped inquiry-based approaches for cognitive and affective learning outcomes.

These findings should nevertheless be interpreted within the study design. Because the quantitative phase employed a single-group pretest–posttest design, the results provide evidence of improvement following AFGLIM implementation, but they do not by themselves establish that AFGLIM was the sole cause of the observed changes. Within that limitation, the convergence of improvements in conceptual understanding, laboratory skills, and motivation provides empirical support for the instructional goals that guided the model's development.

SOP 3- Development of AFGLIM

Development of a flip-guided laboratory instructional model (AFGLIM)

AFGLIM was developed by bringing together the empirical needs identified in the earlier phase of the study and the theoretical principles underlying flipped learning and guided inquiry. The model draws on Piaget's constructivist perspective, Shulman's Pedagogical Content Knowledge (PCK), and research on student-centered laboratory instruction. Its structure responds directly to the difficulties identified by laboratory teachers and PSTs, particularly inadequate preparation before laboratory work, procedural rather than inquiry-oriented activities, limited opportunities for reflection and feedback, and the need for sustained professional development. The resulting model was organized around interconnected components covering pre-laboratory preparation, guided inquiry, post-laboratory reflection and assessment, iterative feedback, and professional growth.

Pre-lab phase: Flipped learning for cognitive readiness

The Pre-Lab Phase uses flipped learning to prepare students conceptually before they enter the laboratory. Rather than devoting substantial laboratory time to introducing foundational content, students engage beforehand with teacher-curated videos, microlectures, digital readings, and concept checks. This structure is grounded in constructivist assumptions about active knowledge construction (Piaget and Inhelder, 1972) and in the importance of cognitive preparation before participation in complex learning activities (Brame, 2013). By activating prior knowledge before experimentation, the phase is intended to leave more laboratory time for investigation, problem-solving, and collaborative work.

This design is consistent with evidence that flipped learning can improve conceptual understanding and motivation by reallocating classroom time toward active and higher-order learning (Akçayır and Akçayır, 2018; Lo and Hew, 2017). It also responds to calls for laboratory education to move beyond "cookbook-style" experimentation toward meaningful scientific inquiry (Hofstein and Lunetta, 2004). In the Philippine context, the model accommodates differences in technological access by allowing preparation to occur through online materials where infrastructure permits or through printable and offline resources where connectivity is limited. This flexibility is important because the value of flipped preparation depends on students' ability to access the learning materials before laboratory sessions.

Formative assessment is embedded within this phase through pre-laboratory quizzes, reflective prompts, and concept checks, consistent with assessment-for-learning principles (Black and Wiliam, 2009). The practical value of this approach was illustrated by one laboratory teacher:

"Before a lab on calorimetry, learners watch a six-minute video that explains specific heat and then fill out a five-question concept check on Google Forms. I change the groups based on outcomes to make sure that students can help each other and quickly go over concepts that were often misunderstood" (LT3).

The account illustrates how pre-laboratory assessment can serve two functions: identifying conceptual difficulties and informing subsequent instructional decisions. The Pre-Lab Phase therefore functions not simply as advance content delivery, but as a mechanism for establishing readiness and directing support before students begin experimental work.

In-lab phase: Guided inquiry and collaborative scientific investigation

The In-Lab Phase shifts the emphasis from following prescribed procedures toward guided scientific investigation. Students formulate hypotheses, consider experimental design, analyze data, and construct evidence-based explanations, while the teacher provides scaffolding through questions, prompts, and feedback. This structure is consistent with constructivist perspectives in which understanding develops through active engagement supported by appropriate guidance (Vygotsky, 1978). The teacher's role is therefore not removed but repositioned-from directing every procedural step to supporting students' reasoning and decision-making.

The use of scaffolding is particularly important because inquiry does not imply minimal guidance. Structured prompts and guiding questions can help novice learners engage productively with complex investigations while gradually developing greater autonomy (Lazonder and Harmsen, 2016). This interpretation is consistent with evidence supporting guided inquiry for higher-order thinking and scientific learning (Furtak *et al.*, 2012; Minner, Levy, and Century, 2010). It also aligns with the emphasis on inquiry and evidence-based reasoning in the Philippine K–12 Science Curriculum (DepEd, 2016), while responding to concerns about continued reliance on verification-oriented laboratory exercises.

The model illustrates this process through laboratory investigations in which students make substantive experimental decisions. For example, during an investigation of reaction rate, the teacher may prompt students with: "What's your control variable? How are you measuring rate consistently?" Rather than providing the answer, such questioning directs attention toward experimental validity and consistency while leaving students responsible for refining their procedure. Collaborative investigation further reflects the social character of scientific practice (OECD, 2019). In this sense, the In-Lab Phase develops laboratory competence while simultaneously modeling an inquiry-oriented pedagogy that PSTs may later apply in their own science teaching (OECD, 2019; NRC, 2012).

Post-lab phase: Metacognition, feedback, and concept reinforcement

The Post-Lab Phase extends laboratory learning beyond completion of the experiment by requiring students to interpret results, evaluate their procedures and conclusions, and connect experimental evidence with scientific concepts. The phase draws on metacognition (Flavell, 1979) and formative assessment (Black and Wiliam, 2009), emphasizing that practical activity becomes educationally meaningful when students have opportunities to examine what they observed, how they reasoned, and what their findings imply.

Structured reflection may include journals, self-assessment, peer discussion, and questions such as "What did I expect to happen and why?", "What evidence supported my conclusion?", and "If I repeated this experiment, what would I change?" Such activities encourage students to reconsider both conceptual understanding and experimental decisions. This emphasis is consistent with literature linking reflection with deeper learning and professional development (Boud, Keogh, and Walker, 2013; Schön, 1983). Teacher feedback further supports this process by addressing procedural errors and conceptual misunderstandings rather than functioning only as a final grade (Hattie and Timperley, 2007).

The phase is particularly relevant to the gaps identified earlier in the study, where PSTs reported limited post-laboratory discussion and reflection. Analytical journals, peer and self-assessment, concept-review tasks, and short quizzes were therefore incorporated to strengthen the transition from experimental experience to conceptual consolidation. These activities align with the inquiry emphasis of DepEd (2016), the outcomes-oriented direction of CHED, and evidence supporting retrieval and consolidation for longer-term learning (Roediger and Butler, 2011). The Post-Lab Phase consequently positions reflection and assessment as integral components of laboratory learning rather than activities added after instruction has effectively ended.

Feedback and iterative learning: A cycle of reflection and improvement

The Feedback and Iterative Learning Phase establishes feedback as a continuing process rather than a single event at the end of laboratory work.

Grounded in formative assessment (Black and Wiliam, 2009), this component emphasizes feedback that is timely, specific, dialogic, and connected to subsequent action. The model incorporates multiple sources—including teachers, mentors, peers, and self-assessment—so that feedback can inform revision of both learning strategies and teaching practice. This orientation is consistent with research emphasizing the contribution of feedback cycles to reflection and instructional improvement (Amani, 2025).

Within teacher preparation, the iterative character of feedback is particularly important. A PST conducting a laboratory teaching demonstration may receive rubric-based feedback on instructional clarity, student engagement, safety, or questioning strategies and then use that feedback to revise and reteach the lesson. This moves feedback from evaluation toward feed-forward improvement, allowing students to act on evidence from one performance in the next. The approach also responds to reported limitations in systematic mentoring and feedback opportunities within Philippine science education (Calixto, Manalo, and Peralta, 2021). In AFGLIM, feedback therefore functions as the mechanism connecting successive learning cycles rather than as a terminal judgment.

Professionalization component: Cultivating teaching identity through authentic practice

The Professionalization Component extends AFGLIM beyond disciplinary learning to the preparation of PSTs as future science educators. It draws on constructivism by PCK (Shulman, 1986), and practice-based approaches to teacher development (Flores and Gago, 2020). Structured reflection, microteaching, mentoring, collaborative planning, and analysis of teaching performance allow PSTs to examine how scientific knowledge is translated into effective laboratory instruction.

Microteaching provides an authentic setting in which PSTs can plan and deliver inquiry-oriented laboratory lessons, receive feedback, revise their teaching, and demonstrate improvement. This iterative process is consistent with collaborative models of professional learning. Mentoring and Professional Learning Communities further support the transition from theoretical preparation to professional practice by creating opportunities for collaborative lesson planning, peer observation, discussion of instructional problems, and resource sharing (Avalos, 2011).

This component is particularly relevant where pre-service teachers have limited opportunities to translate theoretical knowledge into authentic laboratory teaching because of resource constraints, large classes, or restricted practicum opportunities. Professionalization was therefore incorporated as a developmental thread linking laboratory competence, reflective practice, collaboration, communication, ethics, and professional identity rather than as an isolated activity at the end of the model.

Expert validation and iterative refinement of AFGLIM

The development of AFGLIM proceeded through successive rounds of expert review rather than through a single validation event. The initial model was examined by experts who considered its pedagogical coherence, formative assessment structure, feedback processes, professionalization component, terminology, and visual representation. Their comments produced substantive revisions across successive drafts, allowing the model to evolve from a more linear structure toward an explicitly cyclical representation of preparation, inquiry, reflection, feedback, and professional growth.

Expert insights and critique on the first draft of the model

Expert feedback on the first draft centered on three areas: formative assessment, the representation of feedback as an iterative process, and visual and terminological consistency. EXP 1 observed, "The model is good at giving feedback at the end of the Post-Lab phase, but we suggest adding checkpoints earlier, like quick reflections after pre-lab quizzes or during lab discussions." Although this recommendation was consistent with assessment-for-learning principles (Black and Wiliam, 2009), EXP 4 cautioned that "too many assessments may overwhelm both teacher and students." The model was consequently revised to include low-stakes formative checkpoints that could provide useful information without substantially increasing instructional burden (Fig. 7).

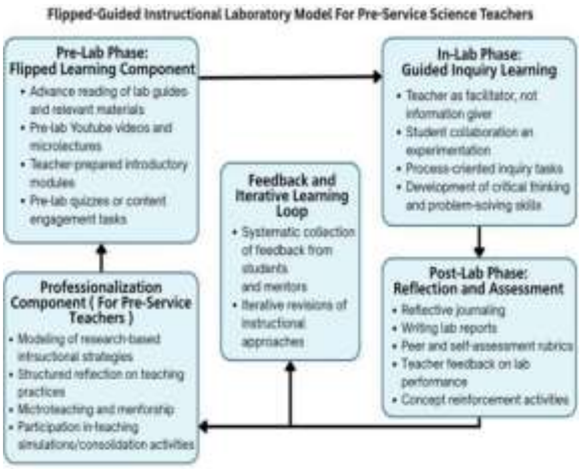

Fig. 7. Initial draft of the model, originally presented in a linear format. This version lacked visual feedback loops and integration of professionalization features, limiting its representation of the continuous and reflective nature of the instructional process. Expert feedback highlighted the need for clearer connections between phases, inclusion of formative assessment, and stronger visual coherence, prompting a redesign toward a more cyclical and interconnected structure.

Feedback was also reconsidered as a cross-phase process. EXP 2 noted, "Learning doesn't stop after Post-Lab activities. Consider showing how the feedback and reflection phase cycles back to improve Pre-Lab planning," while EXP 7 argued that "feedback is not just a phase; it should be woven throughout." At the same time, EXP 5 cautioned against visually "overcomplicating" the framework. These views led to a circular design in which feedback from one cycle informs subsequent preparation, consistent with the recursive character of learning associated with Shulman (1986) and Vygotsky (1978).

Visual coherence was the third major concern. EXP 3 recommended: "The core ideas are solid, but the flow of the diagram could be cleaner. Try using curved arrows or a circular design to better illustrate how the phases are connected. Also, standardizing the model name will help with clarity and academic branding." These recommendations informed the transition to the second draft shown in Fig. 8, which adopted a circular structure, incorporated formative checkpoints, and strengthened cross-phase relationships.

Expert critique and refinement insights on the second draft of the model

Review of the second draft generated further discussion around formative assessment, professionalization, and model identity. EXP 7 reiterated that "Feedback is not just a phase; it should be woven into every phase." Most validators supported embedded formative assessment, although EXP 5 again raised concerns about the practical burden of multiple assessment points. The resulting compromise retained low-stakes tools-such as concept checks, brief reflection journals, and peer critiques-within the Pre-Lab and In-Lab phases (Fig. 8).

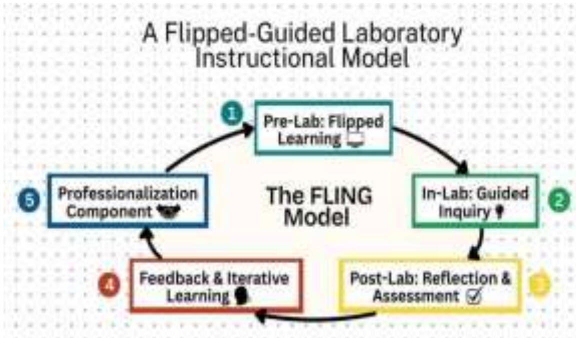

Fig. 8. Second draft of the model showing the transition to a circular layout to emphasize the iterative nature of flipped and guided inquiry learning. Based on expert critique, this version introduced a formative feedback loop across phases, integrated phase-specific icons for better visual clarity, and reframed Phase 5 (Professionalization) as a cross-cutting element linking all phases. These refinements improved consistency, interpretability, and theoretical alignment with the constructivist and reflective practice foundations of AFGLIM.

The placement of professionalization also generated different perspectives. EXP 2 argued, "It shouldn't just be an endpoint—it should be an overlay across the learning process," whereas EXP 4 considered its separate placement useful for highlighting teacher preparation. The revised model therefore treated professionalization as a cross-cutting element while retaining a visible culminating reflective component. This revision preserved the importance of professional preparation without suggesting that professional competence develops only after the laboratory-learning cycle is complete.

Terminological consistency also remained under review. Although validators considered the earlier acronym "FLING" memorable, EXP 1 emphasized that "Clever acronyms work well when their meaning is consistently expanded and connected to the model's purpose." These deliberations contributed to the clearer identity and organization represented in **Fig. 9**, where formative checkpoints, cyclical relationships, and professionalization became more explicit.

Expert insights and critique on the AFGLIM Model (3rd Draft)

The third draft underwent a further cycle of expert review focused on accessibility, scaffolding, reflection, feedback, and professionalization. For the Pre-Lab component, EXP 2 recommended multimodal preparation through "videos, simulations, and simple concept-check quizzes," while EXP 5 cautioned that "too many resource types might overwhelm students with lower digital literacy." The final design therefore incorporated both digital and low-technology alternatives, maintaining the principle of varied preparation without making digital access a prerequisite.

The balance between scaffolding and autonomy was particularly important in the In-Lab component. EXP 6 stated, "Inquiry is at the heart of science education… highlight scaffolding and autonomy as twin pillars of this stage." While some experts favored stronger scaffolding, others cautioned that excessive structure could reduce genuine inquiry. The model consequently adopted tiered scaffolding: novice learners receive clearer prompts and planning tools, with greater autonomy introduced as competence develops.

Fig. 9. Third draft of the model showing a clearer cyclical design with formative checkpoints embedded across all phases and stronger integration of the Professionalization Component. This versionaddressed expert recommendations by refining visual coherence, strengthening the representation of reflective and iterative learning, and ensuring alignment between pre-lab, in-lab, and post-lab tasks. The transition from the FLING label to AFGLIM also clarified the model's identity, emphasizing its anchored focus on flipped and guided inquiry laboratory instruction. These improvements enhanced the conceptual accuracy and practical applicability of the model in teacher education settings.

Reflection and feedback were similarly refined. EXP 7 emphasized, "This isn't just about grading; it's about helping students understand how they learned, what they misunderstood, and how their findings connect to real science problems." EXP 1 further argued, "Feedback isn't a pause point—it's a redirection tool. Make it visible how this phase connects back to both instruction and preparation." The final design therefore retained assessment while strengthening reflective prompts and representing feedback through a clear loop to earlier phases.

On renaming the model: From FLING to AFGLIM

Model identity was reconsidered during expert validation. Although some validators regarded "FLING" as memorable, others questioned whether its connotations were appropriate for an academic instructional framework. EXP 3 stated, "While memorable, the term could suggest casualness or a lack of academic seriousness," while EXP 5 argued that the name "must reflect the integrity and professionalism of a model intended for teacher education research." Conversely, EXP 2 observed that "catchy acronyms aid recall and visibility, especially for pre-service teachers who may easily remember and relate to it."

Fig. 10. Final iteration of the AFGLIM model with standardized terminology, embedded formative feedback and assessment icons, and clear cross-phase linkages representing professional growth integration. This version incorporated validation feedback from experts and implementers, resulting in a visually unified and theoretically grounded framework. Compared to the third draft, it improved naming consistency, reinforced the continuous feedback loop, and made the professionalization thread more visible across all phases. These refinements signify the culmination of AFGLIM's development process—an enhanced instructional model that holistically integrates flipped learning, guided inquiry, and professional reflection.

Following these discussions, the model was renamed AFGLIM (A Flipped-Guided Laboratory Instructional Model) to make its pedagogical foundations more explicit and reduce possible ambiguity. The change was not merely cosmetic; it formed part of a broader effort to establish conceptual and terminological consistency across the framework. As presented in **Fig. 10**, the final version incorporated standardized terminology, formative assessment checkpoints, cyclical feedback, clearer cross-phase relationships, and professional growth as an integrated component.

The Final AFGLIM Model

The final AFGLIM is a cyclical, student-centered framework integrating flipped learning and guided inquiry within science laboratory instruction. Rather than treating laboratory learning as a linear sequence ending with completion of an experiment, the model connects preparation, investigation, reflection, feedback, and professional growth. The circular structure reflects the central developmental principle that evidence from one learning experience should inform preparation and instructional decisions in the next.

1. Pre-lab: Flipped learning

The Pre-Lab component establishes cognitive readiness through videos, readings, quizzes, concept checks, or equivalent offline resources. Students encounter foundational concepts before entering the laboratory, while formative assessment allows teachers to identify misconceptions and adjust subsequent support. The phase therefore combines scaffolding and autonomy: students assume responsibility for preparation while teachers structure resources and readiness checks.

2. In-lab: Guided inquiry

The In-Lab component places experimentation and scientific reasoning at the center of laboratory time. Students investigate problems, formulate explanations, work collaboratively, analyze evidence, and make experimental decisions, while teachers provide guidance when needed. Scaffolding is gradually adjusted according to learner competence, allowing the model to maintain sufficient structure without reducing inquiry to procedural compliance.

3. Post-lab: Reflection and assessment

The Post-Lab component connects experimental experience with conceptual interpretation. Laboratory reports, reflective prompts, self- and peer assessment, and concept-review activities encourage students to evaluate their results, reasoning, and learning strategies. This phase therefore treats assessment not simply as measurement of performance but also as an opportunity for metacognition and conceptual consolidation.

4. Feedback and iterative learning

Feedback operates across the AFGLIM cycle rather than as an isolated endpoint. Teacher, peer, mentor, and self-feedback can redirect students to earlier phases when misconceptions, procedural weaknesses, or instructional difficulties are identified. This recursive structure allows subsequent preparation and laboratory performance to be informed by evidence from previous experience, making improvement an explicit part of the instructional process.

5. Professional growth integration

Professional growth functions as a cross-cutting component of the model. Collaboration, laboratory reporting, communication, research ethics, reflective practice, microteaching, and professional responsibility are developed throughout the learning cycle rather than being confined to a final activity. In this way, AFGLIM connects students' immediate laboratory learning with their longer-term preparation as science educators. The final model therefore integrates disciplinary learning, inquiry competence, reflection, feedback, and professional preparation within a single coherent instructional framework.

CONCLUSION

This study developed and evaluated the A Flipped-Guided Laboratory Instructional Model (AFGLIM) as a context-responsive framework for strengthening chemistry laboratory instruction among pre-service science teachers. The findings show that laboratory instruction in the study context already incorporated elements of learner-centered, active, and inquiry-oriented teaching, but their consistent implementation was constrained by limited equipment and materials, time restrictions, large classes, uneven student preparedness, and limited opportunities for professional development and institutional support. The convergence of laboratory teachers' accounts, PST experiences, survey responses, and external observations indicates that improving laboratory instruction requires more than introducing a new teaching strategy; it requires an instructional structure that connects pedagogy with preparation, laboratory management, feedback, and the realities of the learning environment.

The quantitative findings further indicate that the participating PSTs made measurable gains following the implementation of AFGLIM. Conceptual understanding improved significantly based on the Chemistry Concept Inventory ($t = 2.96$, $p = 0.004$), while laboratory skills measured through the Integrated Science Process Skills Scale showed a significant pretest–posttest improvement ($t = 17.063$, $p < 0.001$). Motivation toward science also shifted positively, with the proportion of students classified as Highly Motivated increasing from 9.2% to 79.3%. Together, these results suggest that the laboratory experience was associated with improvement across conceptual, practical, and affective dimensions of learning. Because the quantitative phase used a single-group pretest-posttest design, however, these gains should be interpreted as improvements observed following AFGLIM implementation rather than as definitive causal effects attributable solely to the model.

The development process resulted in a model that integrates flipped pre-laboratory preparation, guided inquiry during laboratory work, post-laboratory reflection and assessment, continuous feedback and iterative learning, and professional growth integration. Successive expert reviews strengthened the model by embedding formative assessment across the learning cycle, clarifying the balance between scaffolding and learner autonomy, strengthening reflective practice, making feedback explicitly recursive, and positioning professional growth as a cross-cutting component. The transition from earlier drafts to the final AFGLIM therefore reflects an iterative process of empirical grounding, theoretical alignment, expert critique, and refinement rather than the simple combination of flipped learning and guided inquiry.

AFGLIM consequently offers a structured way of connecting what happens before, during, and after laboratory work. Pre-laboratory preparation establishes conceptual readiness; guided inquiry creates opportunities for experimentation, collaboration, and evidence-based reasoning; post-laboratory activities support reflection and conceptual consolidation; and feedback allows weaknesses identified in one learning cycle to inform the next. For pre-service science teachers, the professional-growth component extends these experiences toward their future roles as educators by incorporating reflection, communication, collaboration, laboratory responsibility, and teaching practice. In this sense, the model treats laboratory learning not as the completion of an experimental procedure but as a recursive process in which scientific understanding, practical competence, reflective thinking, and professional preparation develop together.

RECOMMENDATIONS

Based on the study findings and the development and evaluation of AFGLIM, the following recommendations are proposed:

1. For laboratory instructors: AFGLIM may be implemented as a structured laboratory-learning cycle rather than as a set of isolated activities. Instructors should provide focused pre-laboratory materials and readiness checks, use scaffolded guided-inquiry tasks during experimentation, and incorporate post-laboratory reflection and formative feedback. Particular attention should be given to activating prior knowledge and adjusting the degree of scaffolding to students' inquiry experience, as these emerged as areas requiring further instructional support.
2. For teacher education programs and curriculum leaders: AFGLIM may be integrated into chemistry laboratory and science-methods courses through laboratory demonstrations, microteaching, reflective journals, peer feedback, and guided-inquiry lesson development. Professional growth should be embedded throughout the instructional cycle rather than treated only as a culminating activity. Curriculum implementation should also allow sufficient time for pre-laboratory preparation, investigation, analysis, and reflection.
3. For pre-service science teachers: PSTs should use pre-laboratory resources to establish conceptual readiness before experimentation and take an active role in formulating questions, making experimental decisions, analyzing evidence, and evaluating their conclusions. They should also use instructor, peer, and self-feedback to refine subsequent laboratory performance and teaching practice. These activities are particularly relevant to the study's identified needs in practical skills, inquiry experience, and reflective professional preparation.
4. For university and laboratory administrators: Institutional support should prioritize the constraints most clearly identified in the study: insufficient equipment and materials, budget limitations, restricted laboratory space, limited instructional time, and professional-development needs. Resource planning should therefore include maintenance and replenishment of essential laboratory materials, appropriate scheduling and group organization, safety support, and access to suitable digital or offline instructional resources. Because the Laboratory Management Challenges scale showed poor internal consistency (Cronbach's $\alpha = 0.30$), however, the relative severity of individual management challenges should be interpreted cautiously and corroborated through qualitative evidence and further assessment.
5. For professional development providers: Training should move beyond general orientations and provide practice-based support in guided inquiry, flipped pre-laboratory design, formative assessment, scaffolding, laboratory safety and management, and feedback strategies. Mentoring, peer observation, microteaching, and collaborative lesson review should be incorporated so that instructors can apply, evaluate, and refine

AFGLIM-related practices within their own laboratory contexts.

6. For education authorities and policy makers: Any broader adoption of AFGLIM should be preceded by further evidence from different institutional settings rather than assumed from the present study alone. Where the model is adopted or piloted, implementation should be accompanied by adequate laboratory resources, professional preparation, accessible learning technologies, and monitoring of student outcomes. Alignment with relevant CHED and DepEd requirements should be examined at the curriculum and implementation levels rather than assumed solely from the model's theoretical design.
7. For future researchers: Further studies should evaluate AFGLIM using stronger comparative designs, preferably including a comparison or control group, larger and more diverse samples, and implementation across multiple institutions. Future research should report effect sizes and confidence intervals alongside significance tests and examine retention of conceptual understanding, laboratory skills, motivation, and transfer to actual teaching practice. The model should also be evaluated in other science disciplines and under different levels of laboratory-resource availability to establish its transferability and boundary conditions.
8. For further model validation: Future research should examine AFGLIM's implementation fidelity and determine which components—pre-laboratory preparation, guided inquiry, reflection and assessment, iterative feedback, or professional growth integration—contribute most meaningfully to observed outcomes. Longitudinal studies following PSTs into practicum or early teaching would be particularly valuable for determining whether competencies developed through AFGLIM are sustained and transferred to authentic classroom and laboratory settings. Emerging technologies such as AI, virtual laboratories, simulations, and AR/VR may also be investigated, but as extensions to the model requiring empirical evaluation, rather than as assumed improvements.

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REFERENCES

Abrahams I, Millar R. 2008. Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. International Journal of Science Education 30(14), 1945–1969.
DOI: 10.1080/09500690701749305

Abrahams I, Reiss MJ. 2012. Practical work: Its effectiveness in primary and secondary schools in England. Journal of Research in Science Teaching **49**(8), 1035–1055. DOI: 10.1002/tea.21036

Aidoo B, Anthony-Krueger C, Gyampoh AO, Tsyawo J, Quansah F. 2022. A mixed-method approach to investigate the effect of flipped inquiry-based learning on chemistry students learning. European Journal of Science and Mathematics Education **10**(4), 507–518.
DOI: 10.30935/scimath/12339

Akçayır G, Akçayır M. 2018. The flipped classroom: A review of its advantages and challenges. Computers and Education **126**, 334–345.
DOI: 10.1016/j.compedu.2018.07.021

Alake-Tuenter E, Biemans HJA, Tobi H, Mulder M. 2013. Inquiry-based science education competence of primary school teachers: A Delphi study. Teaching and Teacher Education **35**, 13–24.
DOI: 10.1016/j.tate.2013.04.013

Amani NU. 2025. The role of feedback in continuous improvement in schools. Newport International Journal of Current Issues in Arts and Management **6**(1), 134–140.
DOI: 10.59298/NIJCIAM/2025/6.1.134140

American Chemical Society. 2016. Guidelines for chemical laboratory safety in academic institutions. American Chemical Society, Washington, DC.

Avalos B. 2011. Teacher professional development in Teaching and Teacher Education over ten years. Teaching and Teacher Education **27**(1), 10–20. DOI: 10.1016/j.tate.2010.08.007

Baier-Mosch F, Kunter M. 2024. Pre-service teachers' knowledge about classroom management from university studies and own schooling experiences—content and effects of their activation. Frontiers in Education **9**, 1365005. DOI: 10.3389/feduc.2024.1365005

Bergmann J, Sams A. 2012. Flip your classroom: Reach every student in every class every day. International Society for Technology in Education, Washington, DC.

Black P, Wiliam D. 2009. Developing the theory of formative assessment. Educational Assessment, Evaluation and Accountability **21**(1), 5–31. DOI: 10.1007/s11092-008-9068-5

Boud D, Keogh R, Walker D. 2013. Reflection: Turning experience into learning. Routledge, London. (Originally published 1985; 2013 is a Routledge reissue.)

Brame CJ. 2013. Flipping the classroom. Vanderbilt University Center for Teaching, Nashville, TN.

Bransford JD, Brown AL, Cocking RR. 2000. How people learn: Brain, mind, experience, and school: Expanded edition. National Academy Press, Washington, DC. DOI: 10.17226/9853

Braun V, Clarke V. 2006. Using thematic analysis in psychology. Qualitative Research in Psychology **3**(2), 77–101. DOI: 10.1191/1478088706qp063oa

Bybee RW. 2013. The case for STEM education: Challenges and opportunities. NSTA Press, Arlington, VA.

Calixto DCA, Manalo FKB, Peralta RR. 2021. Formative assessment in online distance learning modality through the lens of mathematics and science teachers. IOER International Multidisciplinary Research Journal **3**(3).

Cullin M, Hailu G, Kupilik M, Petersen T. 2017. The effect of an open-ended design experience on student achievement in an engineering laboratory course. International Journal of Engineering Pedagogy **7**(4), 102–116. DOI: 10.3991/ijep.v7i4.7328

Department of Education. 2016. K to 12 curriculum guide: Science (Grade 3 to Grade 10). Department of Education, Republic of the Philippines, Pasig City, Philippines.

Domin DS. 1999. A review of laboratory instruction styles. Journal of Chemical Education **76**(4), 543–547. DOI: 10.1021/ed076p543

Flavell JH. 1979. Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. American Psychologist **34**(10), 906–911. DOI: 10.1037/0003-066X.34.10.906

Flores MA, Gago M. 2020. Teacher education in times of COVID-19 pandemic in Portugal: National, institutional and pedagogical responses. Journal of Education for Teaching **46**(4), 507–516. DOI: 10.1080/02607476.2020.1799709

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. 2014. Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences **111**(23), 8410–8415. DOI: 10.1073/pnas.1319030111

Furtak EM, Seidel T, Iverson H, Briggs DC. 2012. Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. Review of Educational Research **82**(3), 300–329. DOI: 10.3102/0034654312457206

Glynn SM, Brickman P, Armstrong N, Taasoobshirazi G. 2011. Science Motivation Questionnaire II: Validation with science majors and nonscience majors. Journal of Research in Science Teaching **48**(10), 1159–1176.
DOI: 10.1002/tea.20442

Hançer AH, Şensoy Ö, Yıldırım Hİ. 2003. İlköğretimde çağdaş fen bilgisi öğretiminin önemi ve nasıl olması gerektiği üzerine bir değerlendirme. Pamukkale Üniversitesi Eğitim Fakültesi Dergisi **13**(13), 80–88.

Handelsman J, Ebert-May D, Beichner R, Bruns P, Chang A, DeHaan R, Gentile J, Lauffer S, Stewart J, Tilghman SM, Wood WB. 2004. Scientific teaching. Science **304**(5670), 521–522. DOI: 10.1126/science.1096022

Hattie J, Timperley H. 2007. The power of feedback. Review of Educational Research **77**(1), 81–112. DOI: 10.3102/003465430298487

Hodson D. 2014. Learning science, learning about science, doing science: Different goals demand different learning methods. International Journal of Science Education **36**(15), 2534–2553.
DOI: 10.1080/09500693.2014.899722

Hofstein A, Kind PM. 2012. Learning in and from science laboratories. In: Fraser BJ, Tobin KG, McRobbie CJ, Eds. Second international handbook of science education. Springer, Dordrecht, 189–207.
DOI: 10.1007/978-1-4020-9041-7_15

Hofstein A, Lunetta VN. 2004. The laboratory in science education: Foundations for the twenty-first century. Science Education **88(1)**, 28–54.

Hofstein A, Navon O, Kipnis M, Mamlok-Naaman R. 2005. Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. Journal of Research in Science Teaching **42**(7), 791–806.
DOI: 10.1002/tea.20072

Hung HT. 2015. Flipping the classroom for English language learners to foster active learning. Computer Assisted Language Learning **28**(1), 81–96.
DOI: 10.1080/09588221.2014.967701

Justi R, van Driel J. 2005. The development of science teachers' knowledge on models and modelling: Promoting, characterizing, and understanding the process. International Journal of Science Education **27(5)**, 549–573.
DOI: 10.1080/0950069042000323773

Krell M, Krüger D. 2016. Testing models: A key aspect to promote teaching activities related to models and modelling in biology lessons? Journal of Biological Education **50**(2), 160–173.
DOI: 10.1080/00219266.2015.1028570

Kwok PW. 2015. Science laboratory learning environments in junior secondary schools. Asia-Pacific Forum on Science Learning and Teaching **16**(1), Article 9.

Lazonder AW, Harmsen R. 2016. Meta-analysis of inquiry-based learning: Effects of guidance. Review of Educational Research **86**(3), 681–718.
DOI: 10.3102/0034654315627366

Lee H, Kim S. 2017. Implementing dynamic laboratory models in chemistry education: A case study analysis. Chemistry Education Research and Practice **18(4)**, 876–889.
DOI: 10.1039/C6RP00237F

Lo CK, Hew KF. 2017. A critical review of flipped classroom challenges in K–12 education: Possible solutions and recommendations for future research. Research and Practice in Technology Enhanced Learning **12**, 4. DOI: 10.1186/s41039-016-0044-2

Minner DD, Levy AJ, Century J. 2010. Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. Journal of Research in Science Teaching **47**(4), 474–496. DOI: 10.1002/tea.20347

Mulford DR, Robinson WR. 2002. An inventory for alternate conceptions among first-semester general chemistry students. Journal of Chemical Education **79**(6), 739–744. DOI: 10.1021/ed079p739

National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. 1979. The Belmont report: Ethical principles and guidelines for the protection of human subjects of research. U.S. Department of Health and Human Services, Washington, DC.

National Research Council. 2006. America's lab report: Investigations in high school science. The National Academies Press, Washington, DC. DOI: 10.17226/11311

National Research Council. 2012. A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. National Academies Press.

Oh PS, Oh SJ. 2011. What teachers of science need to know about models: An overview. International Journal of Science Education **33**(8), 1109–1130. DOI: 10.1080/09500693.2010.502191

Patel R, Smith DL. 2021. Assessing the impact of inquiry-based laboratory activities on student learning outcomes in chemistry education. Journal of Chemical Education **98(5)**, 1234–1245. DOI: 10.1021/acs.jchemed.0c01384

Piaget J, Inhelder B. 1972. The psychology of the child. Basic Books, New York.

Prince MJ, Felder RM. 2006. Inductive teaching and learning methods: Definitions, comparisons, and research bases. Journal of Engineering Education **95**(2), 123–138. DOI: 10.1002/j.2168-9830.2006.tb00884.x

Roediger HL III, Butler AC. 2011. The critical role of retrieval practice in long-term retention. Trends in Cognitive Sciences **15**(1), 20–27. DOI: 10.1016/j.tics.2010.09.003

Schön DA. 1983. The reflective practitioner: How professionals think in action. Basic Books, New York.

Seery MK. 2015. Moving towards a dynamic chemistry laboratory: Implementing flipped and blended learning. Journal of Chemical Education **92(9)**, 1510–1514.

Shulman LS. 1986. Those who understand: Knowledge growth in teaching. Educational Researcher **15**(2), 4–14. DOI: 10.3102/0013189X015002004

Van Driel JH, Verloop N. 1999. Teachers' knowledge of models and modelling in science. International Journal of Science Education **21**(11), 1141–1153. DOI: 10.1080/095006999290110

Vygotsky LS. 1978. Mind in society: The development of higher psychological processes. Harvard University Press, Cambridge, MA.