



FlipVlab: Integrating Virtual Laboratories, Flipped Learning, and Scientific Inquiry in General Chemistry

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Abstract

General Chemistry learning is often constrained by students' difficulties in understanding abstract concepts and limited access to laboratory activities, highlighting the need for flexible digital learning environments that connect conceptual preparation with experimental inquiry. This study developed and evaluated FlipVlab, an integrated learning model that combines virtual laboratories, flipped learning, and scientific inquiry for General Chemistry. The model structures learning through pre-class digital preparation and virtual experimentation, followed by in-class data verification, collaborative analysis, and conclusion formulation. FlipVlab was developed using an integrated research and development framework and underwent formative evaluation through expert review, individual evaluation, and small-group evaluation. Its feasibility was assessed by experts in instructional design, learning materials, and learning media, while its effectiveness was examined through a quasi-experimental post-test-only control-group design. The findings demonstrated that FlipVlab achieved high feasibility across all evaluated components. Students learning through FlipVlab also achieved substantially better learning outcomes than those receiving conventional instruction, with the observed difference indicating a strong educational effect. These findings suggest that systematically integrating virtual experimentation with flipped learning and scientific inquiry can provide an effective alternative for General Chemistry instruction, particularly when physical laboratory access is constrained. FlipVlab offers a structured model for connecting online preparation, digital experimentation, and collaborative classroom inquiry.

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INTRODUCTION

Basic Chemistry is widely recognised across higher education systems as a challenging 'gatekeeper' course, associated with persistently high failure and attrition rates that affect student retention in science and STEM disciplines in various countries (Basu et al., 2025). This is especially important in Basic Chemistry courses, where laboratory activities play a crucial role in helping students understand abstract chemical concepts and develop scientific reasoning skills. However, the implementation of laboratory learning in Basic Chemistry often encounters practical constraints such as limited laboratory facilities, restricted time allocation, and limited opportunities for active experimentation (Mosiienko et al., 2023; Duangsopa & Nuangchalerm, 2024). Therefore, the teaching of Basic Chemistry requires an instructional approach capable of maintaining experimental activities

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that are easily accessible and flexible (Hardani et al., 2025; Jasper et al., 2023). A preliminary study conducted across six universities offering Science Education Programs in Central Java and Yogyakarta (consisting of four public universities and two private universities) through document analysis of course assessment records and informal interviews with course instructors revealed that students in four of the six programs achieved Basic Chemistry examination scores below 65.

Beyond these conceptual and instructional challenges, practical constraints within traditional laboratory environments further hinder student learning. Limited laboratory facilities and restricted instructional time can constrain students' opportunities to engage meaningfully in experimental learning. These persistent constraints highlight the need for alternative laboratory approaches that can provide more flexible and personalised learning experiences. Empirical evidence demonstrates that virtual laboratory environments can significantly improve students' conceptual comprehension and problem-solving abilities (Aliyu & Talib, 2019; Chen et al., 2024; Maiyanti et al., 2025; Penn & Ramnarain, 2019; Widarti et al., 2022). Furthermore, when physical laboratory activities are limited due to facility constraints, virtual alternatives help maintain continuity in learning and support the visualisation of abstract chemical concepts (Hudha et al., 2025; Penn & Ramnarain, 2019; Solikhin et al., 2019). However, these studies share a common methodological limitation.

Virtual laboratories were evaluated primarily as standalone instructional media, with effectiveness assessed through direct comparison to physical laboratory activities (Penn & Ramnarain, 2019) or through general usage outcomes (Aliyu & Talib, 2019; Chen et al., 2024; Baihaqi & Arimurti, 2025), rather than being embedded within a broader pedagogical structure that governs how pre-class preparation, in-class inquiry, and data confirmation are sequenced. A smaller body of research has attempted to combine virtual laboratories with flipped classroom pedagogy. For instance, Kavitha & Anitha (2023) integrated a virtual laboratory within a flipped classroom to support the CDIO (Conceive–Design–Implement–Operate) framework in an engineering theory course, while Chen et al. (2025) embedded a structured, inquiry-based virtual laboratory within a flipped physics classroom to enhance learning achievement, motivation, and inquiry skills. These studies demonstrate that combining virtual laboratories with flipped classroom strategies can be pedagogically productive; however, both were developed for disciplines and instructional contexts outside Basic Chemistry, and neither explicitly articulates a scientific inquiry sequence with clearly defined instructional syntax, social system, and support system components in the way emphasised by instructional design frameworks such as Dick, Carey, and Carey (2001). This suggests that, while the combination of virtual laboratory and flipped classroom approaches is not entirely novel, its systematic integration within a scientific inquiry framework (with an explicitly defined instructional model rather than an ad hoc combination of strategies) remains underexplored, particularly within Basic Chemistry education (Pranata, 2024).

Therefore, this study proposes FlipVlab as an integrated learning model that combines virtual laboratory utilisation, scientific inquiry processes, and flipped classroom strategies to provide a more structured and pedagogically grounded approach to Basic Chemistry instruction (Riadi et al., 2024). In response to these challenges, the researchers propose the development of a learning model that integrates a Virtual Laboratory with a Flipped Classroom design for the Basic Chemistry course. A Virtual Laboratory enables students to conduct digital experiments anytime and anywhere, thereby addressing laboratory facility limitations and offering a feasible alternative for institutions with restricted access to physical laboratories (Limba et al., 2023; Pathak et al., 2025; Ramadani et al., 2025; Yogaswara et al., 2025). Virtual laboratories also provide students with structured preparation prior to physical laboratory sessions, effectively reducing in-lab time and allowing more student groups to rotate efficiently (Hamed & Aljanazrah, 2020). The Flipped Classroom, as part of blended learning, complements this approach by requiring students to engage with learning materials independently before class, allowing in-class sessions to focus on deeper discussion and conceptual application (Bergmann & Sams, 2012; Gunawan & Yumiarty, 2026; Rahdi et al., 2025). Research indicates that the Flipped Classroom improves conceptual understanding and encourages more active participation during face-to-face learning (Awi et al., 2025; Islami, 2024; Karapınar et al., 2023; Wibowo & Subagiyo, 2022).

Together, the Virtual Laboratory and Flipped Classroom can be integrated into a comprehensive learning model that supports instructional strategies, teaching methods, and interaction patterns between lecturers and students. Such a model offers a more holistic pedagogical framework than the use of digital media alone, which typically emphasises tools rather than the broader instructional process (Azizah & Aziz, 2024; Muhibbuddin et al., 2026). However, previous studies have generally examined virtual laboratories and flipped classrooms separately or have focused primarily on their effectiveness as instructional media rather than integrating them into a structured learning model with clearly defined pedagogical components. Research that systematically integrates virtual laboratory use, flipped learning strategies, and scientific inquiry processes into a unified instructional model for Basic Chemistry remains limited. FlipVlab distinguishes itself by integrating virtual laboratory activities into a scientific inquiry process and structuring them through a flipped classroom approach. This model is defined not only by its integration of media but also by its learning syntax, social system, principles of reaction, support systems, and learning outcomes. Its innovative procedure lies in combining pre-class virtual experiments, initial readiness assessments, in-class data verification, collaborative analysis, and conclusion formulation into a coherent learning flow for Basic Chemistry.

Therefore, this study aims to develop and evaluate the feasibility and effectiveness of FlipVlab as an integrated learning model that combines Virtual Laboratory and Flipped Classroom approaches in Basic Chemistry learning. Unlike prior virtual-laboratory studies that evaluate the medium in isolation (Aliyu & Talib, 2019; Penn & Ramnarain, 2019) or prior virtual-laboratory-flipped-classroom combinations developed outside Basic Chemistry without an explicit inquiry structure (Kavitha & Anitha, 2023; Chen et al., 2025), FlipVlab's novelty lies in its explicit definition as a complete instructional model (encompassing instructional syntax, a social system, reaction principles, and a support system) that systematically embeds virtual laboratory use and flipped-classroom sequencing within a scientific inquiry framework specifically designed for Basic Chemistry instruction. In addition, this study provides empirical evidence regarding the feasibility and effectiveness of the model in supporting meaningful Basic Chemistry learning.

METHOD

This study applied a Research and Development (R&D) design that combined the instructional design models of Dick, Carey, and Carey (2001) and Borg and Gall (2003). The combination of these stages aims to strengthen the empirical and theoretical foundations of the learning model's development. The integrated procedure consists of eleven development stages, beginning with research and information collection and ending with summative evaluation. A detailed illustration of the integrated development stages is presented in Figure 1.

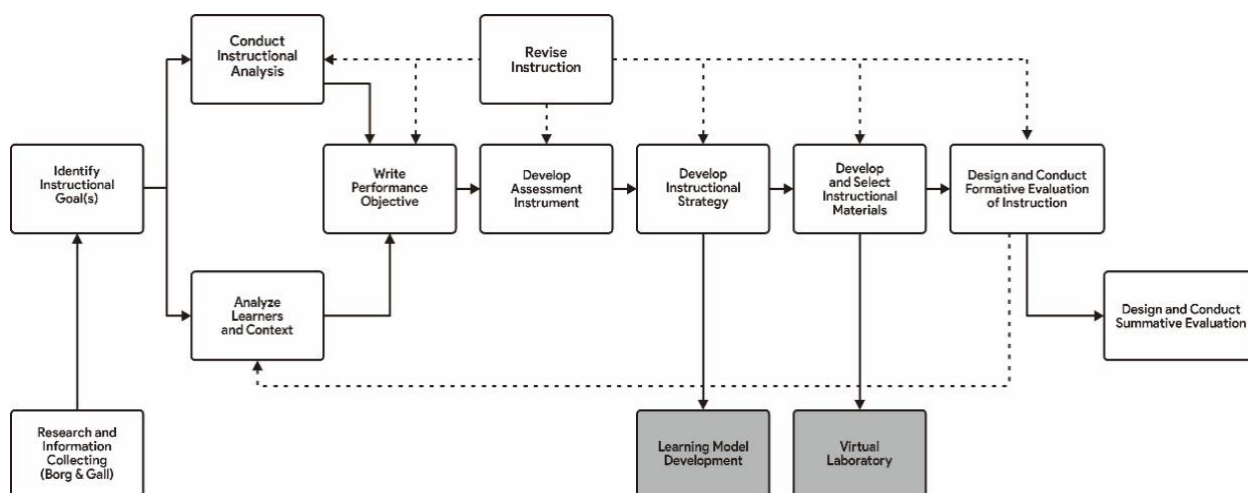


Figure 1. Learning Design Development Framework

Preliminary Study

Prior to the development of the FlipVlab learning model, a preliminary study was conducted as part of research and information collection (stage 1). The preliminary study involved six universities in Central Java and Yogyakarta that offered undergraduate Science Education programs, consisting of four public universities and two private universities. The informants were lecturers responsible for teaching Basic Chemistry courses at the participating programs. The data sources included Basic Chemistry course assessment records, course documents, and informal interviews with course lecturers regarding learning challenges, laboratory implementation, and the use of digital learning media. Data collection was carried out by reviewing available course assessment records and course documents, followed by informal interviews with lecturers to clarify the learning conditions and constraints identified from the documents. The examination score data were analysed descriptively by identifying programs in which students' average Basic Chemistry scores were below the minimum criterion of 65. The interview data were analysed qualitatively by summarising recurring issues related to conceptual difficulty, limited laboratory facilities, insufficient laboratory time, and minimal integration of digital learning tools.

Learning Models Design

The draft learning model was designed up to stage 8, with each design decision directly informed by the needs identified in the preliminary study. The limited availability of laboratory facilities and insufficient in-class laboratory time were addressed by relocating initial experimentation to a virtual laboratory conducted independently before class (the Collecting Data stage), thereby reducing dependence on the single physical laboratory available and reserving limited in-class laboratory time specifically for data-confirmation activities. The minimal integration of digital learning tools identified among lecturers was addressed by structuring pre-class preparation entirely through the Learning Management System (the Preparing to Learn stage), ensuring that digital delivery was embedded as a core instructional component rather than a supplementary tool. The persistent conceptual difficulty reported by lecturers was addressed by introducing an Initial Assessment stage prior to face-to-face instruction, allowing instructors to identify students' misconceptions in advance, and by structuring in-class time explicitly around data confirmation, analysis, and conclusion-drawing (the Confirming Data, Analysing, and Concluding stages) rather than initial content delivery, thereby allocating more instructional time to addressing conceptual gaps. Collectively, this sequence was designed to maximise students' cognitive engagement by shifting conceptual introduction to pre-class activities and allocating classroom time for deeper exploration and data-driven discussions supported by virtual laboratory environments.

Evaluation of the Draft Learning Models

The evaluation of the learning model draft was carried out in stage 9, namely Design and Conduct Formative Evaluation. Formative evaluation consisted of expert review, one-to-one evaluation, and small-group evaluation following Tessmer (1993). The product will be evaluated by several parties to determine its readability and practicality. The components evaluated in the FlipVlab learning model consist of: (1) the implementation of the learning model syntax compiled in the Lecture Teaching Unit; (2) digital learning materials covering Basic Chemistry content and virtual laboratories; (3) evaluation tools designed to measure student learning outcomes in Basic Chemistry courses; and (4) the Learning Management System used (Google Classroom). Products that have undergone qualitative evaluation require a quantitative assessment; therefore, the same experts provide an expert judgment to determine the product's feasibility score.

Expert Review

Expert review is a stage of reviewing and evaluating learning model products conducted by experts, including 1) three instructional design experts, 2) three learning material experts, and 3) three learning media experts. The experts were selected based on their academic qualifications, professional experience, and relevance of expertise to the developed model. The selection criteria included holding a doctoral degree in a relevant field, having at least five years of teaching or research experience, and having publications or professional work related to instructional design, chemistry

education, or educational technology. All experts were affiliated with reputable universities. The experts provided qualitative feedback on the product, and the results of their review formed the basis for improvements to the learning model being developed.

One-To-One Evaluation

One-to-one evaluations were conducted through structured interviews with three students who had completed the Basic Chemistry course, selected using a maximum variation sampling strategy to capture perspectives across different levels of academic ability. Ability level was determined based on the scores from the most recent basic chemistry exam, which were categorised into below-average, average, and above-average groups. Three students representing below-average, average, and above-average achievement levels participated in the one-to-one evaluation.

Small Group

In this process, nine different students who took the Basic Chemistry course were selected. These nine students consisted of three students with below-average ability, three with average ability, and three with above-average ability. These students were divided into three groups, each consisting of one student from each ability level. They were then given learning activities designed to test the practicality of the FlipVlab learning model and its supporting system. The instrument used in this stage was the same as in the one-to-one stage: a structured interview guide covering the same five dimensions. The difference was that the interviews were conducted with each group separately. The feedback and responses from the student groups were summarised and analysed to inform revisions.

Expert Judgment

The feasibility of the FlipVlab learning model was assessed based on expert judgment. The results of the formative evaluation conducted previously served as the basis for improving the research product. After the product was improved, the researchers resubmitted it to the same nine experts (three per aspect: instructional design, learning materials, and learning media) for expert judgment. At this stage, the FlipVlab learning model was assessed quantitatively using the instruments provided.

Effectiveness of Learning Models

The learning model that was evaluated was implemented through a field trial, namely, implementation through basic chemistry learning in the classroom. At the end of the learning process, a summative evaluation was conducted in accordance with stage 11. The effectiveness of the learning model was tested at this stage. For this reason, this study also adopted a quantitative research design with a quasi-experimental method using a post-test-only control group design. The implementation involved an experimental class that applied the FlipVlab learning model and a control class that received conventional instruction. Although the control class's teaching plan formally designated Problem-Based Learning, classroom implementation in practice followed a lecture-based format consisting of direct explanation of course material, structured worksheet exercises, and quizzes, without the defining stages of PBL (e.g., problem orientation, guided investigation). The control condition is therefore characterised in this study based on its implemented instructional activities rather than its nominal designation. The study involved 39 students in the experimental class and 38 students in the control class, selected using purposive sampling based on class availability. The research instrument consisted of a Basic Chemistry achievement test developed based on course learning outcomes and validated by experts. The effectiveness data were analysed using an independent samples t-test after fulfilling normality and homogeneity assumptions. In addition, Cohen's *d* effect size was calculated to determine the magnitude of the model's effectiveness.

Design of the FlipVlab Learning Model

The learning model was designed up to stage 8. The strategies and materials in the learning model were designed based on the results of the previous stages, namely ensuring alignment with learning goals, learner characteristics, and required performance outcomes. The model was developed to address the challenges commonly encountered in Basic Chemistry instruction, particularly limited laboratory access, time constraints, and low conceptual mastery. The strategy was organised into a structured learning sequence (syntax) that combines pre-class preparation, in-class virtual experimentation, and post-class consolidation. This sequence was designed to maximise students' cognitive engagement by shifting conceptual introduction to pre-class activities and allocating classroom time for deeper exploration and data-driven discussions supported by virtual laboratory environments.

The model developed in this study is a learning model intended for use in the Basic Chemistry course within the Science Education undergraduate program. It is grounded in the syntax of the scientific inquiry learning model. It incorporates a virtual laboratory as a digital experimental medium to provide an alternative to the limited availability of physical laboratory activities. In addition, the learning model is implemented using a flipped classroom approach to offer students additional independent online learning time before class sessions begin, thereby promoting more active and cooperative participation during in-class learning activities. The foundational learning model for this study is the Scientific Inquiry model, which is classified as an information-processing learning model according to (Joyce & Weil, 2003). The stages of the Scientific Inquiry are as follows:

Phase One: An area of investigation is posed to students. In this initial phase, students are introduced to an area of investigation, including the methodology that will be used to conduct the inquiry. *Phase Two: Students structure the problem.* During this phase, students organise the problem in such a way that they can identify the specific challenges involved in the investigation. These challenges may relate to data interpretation, data collection, experimental control, or the formulation of inferences.

Phase Three: Students identify the problem in the investigation. In this phase, students are encouraged to speculate about the problem so they can clearly identify the difficulties associated with the inquiry. *Phase Four: Students speculate on ways to clear up the difficulty.* In the fourth phase, students are asked to propose possible solutions to the difficulties identified. These may include redesigning the experiment, reorganising or generating data, developing conceptual constructs, and other strategies aimed at resolving the investigative challenge. The learning model developed in this study applies a flipped classroom approach. The implementation procedures, adapted from (Talbert & Bergmann, 2017), are as follows:

Online Meeting (Before Class)

Part 1 focuses on students accessing and studying course materials online. The type of material provided depends on the topic being discussed. In addition to the primary textbook, students are given supplementary readings and instructional videos. Part 2 involves students completing an initial online assessment. This assessment allows the lecturer to review students' preliminary responses and identify areas that require further clarification.

Face-to-Face Meeting (In-Class Session)

Part 3 consists of face-to-face sessions in which the lecturer minimises direct lecturing. Instead of relying on traditional lecture methods, the in-class focus is on interactive discussion rather than content delivery. Part 4 comprises collaborative learning activities. These activities include pro-con debates, case study analyses, and process-oriented exercises designed to strengthen conceptual understanding. The learning model developed in this research incorporates a virtual laboratory as an alternative means to maintain experimental activities that are often limited in science instruction. This approach enables more in-depth and detailed learning during in-class sessions. Based on this integration, the conceptual design developed in this study is referred to as the FlipVlab model (Flipped Classroom and Virtual Laboratory). The model is illustrated in Figure 2.

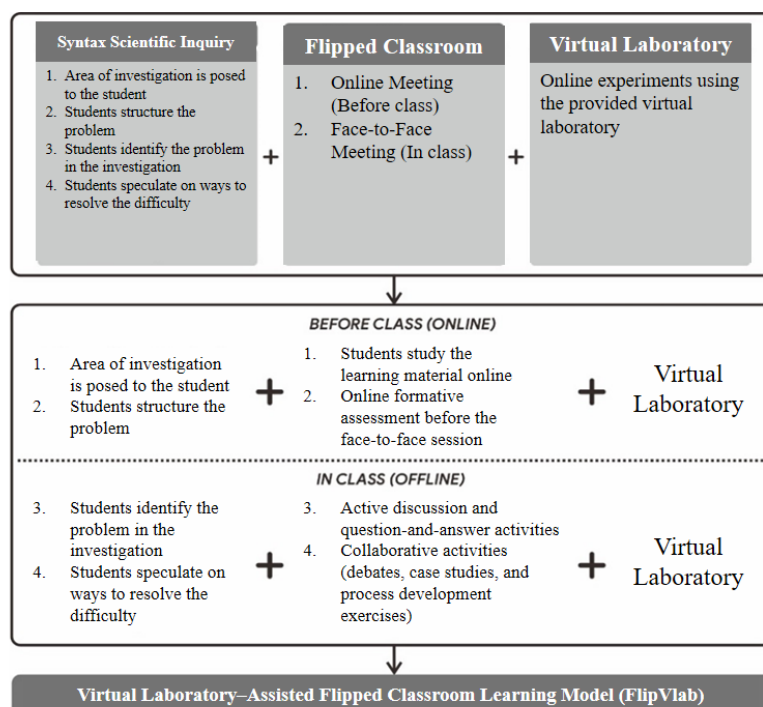


Figure 2. Conceptual Model Framework

The design of the FlipVlab learning model demonstrates strong theoretical coherence with the principles of scientific inquiry and the pedagogical foundations of the flipped classroom approach, resulting in an instructional framework that is both structurally robust and pedagogically responsive. By integrating the inquiry-based phases, which include posing the area of investigation, structuring the problem, identifying investigative challenges, and proposing solutions, with pre-class digital preparation, the model ensures that students enter inquiry activities with prior conceptual exposure and procedural familiarity. This design approach is consistent with earlier studies that emphasise the benefits of self-paced engagement with digital materials such as videos, simulations, and tutorials, which help learners internalise theoretical content and laboratory procedures before attending class (Baillie et al., 2022; Coakley, 2024; Mellefont & Fei, 2016).

The inclusion of virtual laboratory activities during the pre-class phase also strengthens this alignment. Virtual labs and simulations support the visualisation and exploration of complex scientific phenomena in dynamic and interactive formats, a finding that has been well documented in previous research (Chen et al., 2025; Kavitha & Anitha, 2023; Kolil & Achuthan, 2024). Collectively, these features position FlipVlab as a learning model that prepares students cognitively for inquiry work while also serving as an effective alternative to physical laboratory activities. Within the in-class component of the model, the design prioritises interactive discussion, collaborative inquiry, and problem-focused engagement rather than conventional lecture delivery. This arrangement corresponds with prior investigations that highlight the value of active learning environments in enhancing analytical engagement and knowledge application (Coakley, 2024; Portillo et al., 2025; Putri et al., 2019).

The structure of FlipVlab also creates intentional opportunities for students to address investigative difficulties identified during earlier stages of the inquiry cycle while receiving immediate guidance from instructors. This aligns with literature emphasising the importance of timely clarification and feedback in learning environments that incorporate digital laboratory elements (Baillie et al., 2022; Montalbano & Marinelli, 2019). The model additionally anticipates common challenges associated with flipped classroom implementation, particularly the need for high-quality preparatory materials and clear communication of expectations. Earlier studies note that these factors are essential for sustaining student engagement with pre-class tasks, and the structured digital resources and guided inquiry phases included in FlipVlab provide direct responses to these concerns (Baillie et al., 2022; Mellefont & Fei, 2016).

Another recognised challenge in flipped learning involves balancing student workload. The model accommodates this issue by integrating flexibility into pre-class activities and by offering interactive and motivating in-class tasks, which reflects recommendations found in the literature for maintaining learner motivation and managing cognitive demands. Based on the conceptual framework outlined above, a new instructional syntax was developed to support the FlipVlab learning model. In addition to this syntax, the FlipVlab design also incorporates a social system, a set of reaction principles, a support system, and defined instructional impacts. These components align with the essential elements of a learning model as described by Joyce and Weil, and they further strengthen the coherence of FlipVlab as an integrated inquiry-based and digitally enhanced instructional framework.

The Syntax of the FlipVlab Science Learning Model

The syntax of the FlipVlab learning model is organised into a series of interconnected stages that integrate online and face-to-face learning to guide students through a coherent process of scientific inquiry. To provide a clearer understanding of the structure and sequence of the proposed learning model, the syntax of the FlipVlab Learning Model is illustrated in Figure 3. The figure presents the key learning phases and their systematic progression throughout the learning process.

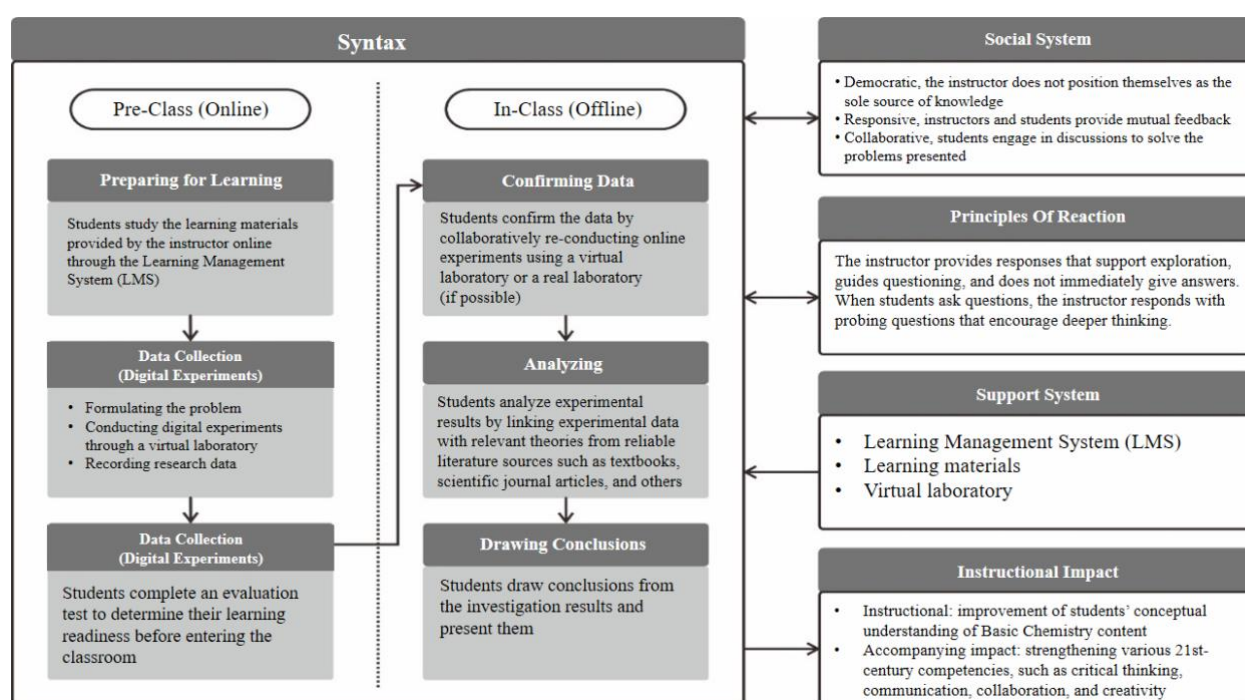


Figure 3. Syntax of the FlipVlab learning model

The sequence begins with pre-class activities conducted online, where learners engage with instructional materials and perform virtual experiments, and continues into in-class sessions, where they confirm data, analyse results, and construct scientific conclusions through guided collaboration. Each component of the syntax is deliberately designed to build on the previous one, ensuring continuity between virtual exploration and classroom-based reasoning. The following description outlines each step of the FlipVlab syntax as a unified and coherent instructional sequence.

Pre-Class (Online) via the Learning Management System (LMS)

Preparing to Learn

In this stage, learners study the instructional materials provided online through the LMS. These materials may include videos, animations, texts, and other resources. Learners are then given investigative prompts by observing scientific phenomena.

Collecting Data (Virtual Experiment)

At this stage, students formulate research questions based on scientific phenomena observed during the previous stage. Students then develop a tentative hypothesis and test it through virtual experiments using the provided virtual laboratory. The experimental results are recorded as research data and will be discussed during the data confirmation stage in the next face-to-face class.

Initial Evaluation

In this stage, learners are assessed to determine their readiness for in-class learning. The evaluation is prepared by the instructor through individual tests or assignments.

In Class (Offline/Face-to-Face)**Confirming Data**

In this stage, learners meet face-to-face to verify and discuss the data obtained from the pre-class virtual experiment. They collaboratively repeat the virtual experiment, or conduct a real laboratory experiment, when possible, to confirm the consistency and reliability of the data. This stage is intended to compare the experimental findings with the hypotheses formulated earlier and to prepare students for deeper analysis.

Analysing

Here, learners analyse their experimental results by connecting them to theoretical concepts from credible literature sources such as textbooks and scientific journal articles. The instructor provides guidance and reinforces the analytical processes carried out by the learners.

Concluding

In this stage, learners conclude their investigation and present it. The presentation may take the form of a written report or a class presentation. The description of the FlipVlab syntax also leads to the need for understanding the elements that shape how this sequence is experienced by learners. The effectiveness of each stage in the syntax is influenced by the interaction patterns established in the learning environment, the ways instructors respond to students' reasoning, and the various supports that enable both online and face-to-face activities to run effectively. To present a complete picture of how the FlipVlab model operates in practice, the following discussion outlines the social dynamics, reaction principles, support structures, and instructional outcomes that work alongside the syntax to create a coherent learning experience.

Social System

The FlipVlab Learning Model is designed to create a democratic, responsive, and collaborative learning environment that supports students' learning needs. In this social system, interactions between students and instructors are democratic; instructors do not position themselves as the sole source of knowledge but act as facilitators who guide the learning process. Students are given space to express ideas, ask questions, and discuss experimental data with their peers in a responsive manner. This environment encourages learners to engage actively with scientific problems and to negotiate meaning through dialogue rather than relying on direct instruction. Collaborative exchanges also help students refine their reasoning by comparing perspectives, evaluating evidence, and challenging assumptions in a supportive setting (Abirami & Kiruthiga, 2018). Such social dynamics foster a sense of shared responsibility for learning and help cultivate communication skills that are essential for scientific inquiry (Abirami & Kiruthiga, 2018; Khusna et al., 2025).

Principle of Reaction

The instructor's reaction principle in this model emphasises the reinforcement and cultivation of scientific thinking. Instructors are expected to respond in ways that encourage exploration rather than simply delivering information. This includes guiding students' questions, prompting them to articulate their reasoning, and deliberately avoiding direct or immediate answers that could limit inquiry. When students pose questions or present observational data, instructors respond with counter-questions that help learners examine the basis of their ideas, identify gaps in their understanding, and consider alternative explanations. Such responses are intended to stimulate

deeper cognitive engagement, support the development of hypothesis-driven reasoning, and encourage students to validate their assumptions through evidence rather than relying on authority. Through this approach, the instructor's role becomes central in shaping a learning environment where curiosity, critical analysis, and reflective thinking are continuously fostered (Karimi & Manteufel, 2017).

Support System

The successful implementation of the FlipVlab model relies heavily on a comprehensive support system. The primary component is the Learning Management System (LMS), which functions as the central platform for distributing materials, collecting assignments, conducting initial evaluations, and facilitating online interactions between instructors and students. The learning materials available in the LMS include instructional videos, interactive animations, scientific texts, and digital worksheets that support students' initial exploration of Basic Chemistry concepts. The virtual laboratory is another key element. This medium is designed as an interactive two-dimensional simulation that allows students to perform digital experiments, collect data, and observe phenomena safely and flexibly. To support the in-class learning process, real laboratory equipment (when available), experiment guides, assessment rubrics, and reference materials (journal articles, textbooks, etc.) are also provided for use during the analysis and conclusion stages.

Instructional Impact

The instructional impact of this learning model is evident in the enhanced development of students' conceptual understanding in Basic Chemistry. The systematic integration of virtual experiments, structured collaborative discussions, and dual-mode learning environments (online and offline) enables students to engage with chemical concepts through multiple learning experiences. Virtual experiments allow students to visualise abstract phenomena, test theoretical ideas in a controlled setting, and repeat investigations when needed, thereby supporting deeper conceptual comprehension. Collaborative discussions further strengthen understanding by encouraging students to articulate their reasoning, compare interpretations, and negotiate meaning with peers, which helps clarify misconceptions and reinforce scientifically accepted concepts. The use of both online and face-to-face learning modes also provides flexibility and continuity in learning, allowing students to access materials, revisit content, and reflect on their understanding at their own pace.

Beyond its direct instructional outcomes, this learning model is theoretically expected to yield accompanying benefits for students' affective and social development. Sustained interaction and shared problem-solving activities have been associated in the broader literature with the development of positive learning attitudes, collaborative skills, and social competencies. The learning process requires students to take greater responsibility for their own learning, as they must prepare before class, actively participate during discussions, and reflect on feedback afterward. Similarly, repeated engagement with experimental data and peer arguments is theorised to foster habits of verifying evidence rather than relying on assumptions (Jin et al., 2023), and to support the cultivation of scientific attitudes such as objectivity, accuracy in data interpretation, and openness to disconfirming findings (Walker & Wolf, 2017). Collectively, these theoretical considerations suggest that the learning model has the potential to support the holistic development of students as independent, reflective, and scientifically minded learners; however, the present study focuses specifically on measuring students' cognitive learning outcomes, and these broader affective and social dimensions were not directly assessed.

RESULTS AND DISCUSSIONS

Evaluation of FlipVlab Learning Model

Expert Review Results

The expert review was conducted qualitatively by experts, including 1) three instructional design experts, 2) three learning material experts, and 3) three learning media experts, on the FlipVlab learning model. For the instructional design aspect, experts identified as strengths the model's capacity to support collaborative activities, independent learning, and scientific concept understanding through relevant media. The main weakness noted was the incompleteness of non-

cognitive evaluation instruments and insufficient elaboration of collaboration-related components. In response, the researchers strengthened the collaborative components of the model by incorporating group-based laboratory sessions (in-person and online) and requiring students to analyse experimental data through structured questions provided in the student worksheets. A non-cognitive evaluation instrument could not be incorporated, as this study specifically focused on measuring students' cognitive abilities in Basic Chemistry; this recommendation remains a consideration for future research. For the learning materials aspect, the main strength identified was the appropriateness and relevance of the content to course objectives. The primary weakness was the absence of a complete outline accompanied by a scoring rubric and answer key; in response, the researchers compiled and incorporated a complete outline, rubric, and answer key into the revised materials.

For the learning media aspect, experts identified as a strength the effectiveness of the media in supporting both pre-class and in-class learning. The main weakness identified was the absence of supplementary elements, namely a material summary, a learning checklist, and instructions for using the virtual laboratory. In response, the researchers added a material summary and virtual laboratory usage instructions to the revised media. A learning checklist could not yet be incorporated, as this feature was not available within the Learning Management System (LMS) used in this study; this recommendation remains a consideration for future development.

One-To-One Evaluation Results

One-to-one evaluations were conducted qualitatively by three students with different ability levels on the FlipVlab learning model. Overall, the students' responses to the FlipVlab learning model were entirely positive; all three students stated that the model helped them learn Basic Chemistry through the scientific method presented via digital experiments. The students generally reported positive perceptions of the model, while unclear virtual-laboratory instructions were identified as an area requiring revision. However, the students also identified an area that needed improvement: the instructions for using the virtual lab, which were still confusing. These comments collectively served as the basis for minor revisions prior to the small-group evaluation, and the model was deemed suitable to proceed to the next stage.

Small Group Evaluation Results

In the small group stage, basic chemistry learning was simulated using the FlipVlab model. There were three groups of students with different levels of ability. Each student was given an evaluation instrument and filled it out after the learning was completed. The evaluation results showed variations in opinions from each group representative regarding the FlipVlab learning model provided. There were several shortcomings felt by the students during the implementation of learning. All student suggestions were addressed. Concept maps, videos of chemical phenomena, infographics, and other digital experiments have been added to the course materials. The course materials have also been optimised for access on both PCs and smartphones, with improved visual quality and language. As for the discussion forums, they are already available on the LMS; instructors simply need to highlight them. These discussion forums serve as a platform for online collaboration. Although several aspects still require improvement, students expressed positive perceptions of the FlipVlab learning model. They indicated that the online learning preparation, digital/laboratory experiments, and collaborative experimental data analysis activities in class presented by this learning model supported their cognitive understanding in Basic Chemistry courses. Thus, after improvements, the FlipVlab learning model can proceed to the next stage.

Expert Judgment Results

The results of the evaluation of the FlipVlab learning model were revised, and then a quantitative expert judgment was conducted by the nine experts mentioned earlier. This expert evaluation instrument uses a rating scale (1-4) to assess the suitability of three aspects: instructional design, learning materials, and learning media. Each aspect consists of several items based on indicators specific to that aspect. The score obtained for each aspect is calculated by dividing the total score of the items assigned by the relevant experts by the maximum possible score. There are three experts for each aspect; thus, the final score for each aspect is the average of the scores given by each

expert. The final scores are then converted into percentages. The results of the expert judgment can be seen in Table 1.

Table 1. Expert Judgment Results

Aspect	N Items	Experts' score			AVG	Max Score	%	Category
		1	2	3				
Instructional Design	24	87	91	96	91.33	96	95.14	Excellent
Learning Material	21	74	84	78	78.67	84	93.65	Excellent
Learning Media	19	72	73	72	72.33	76	95.18	Excellent

Note: The feasibility category was determined using the following criteria: 76–100 = Excellent, 50–75 = Good, 26–49 = Poor, and <26 = Very Poor.

Based on the data presented in Table 1, the aspects of instructional design, learning materials, and learning media each received an average rating of “excellent” from the experts. This outcome demonstrates a high level of consistency across the three evaluated components and confirms that the FlipVlab learning model meets the feasibility criteria.

The instructional design component received the highest evaluation score (95.14%), indicating alignment between learning objectives and needs, as well as coherence in the flow of the instructional model and its components. The learning materials component (93.65%) was assessed as sufficiently detailed, accurate, up-to-date, and well-organised. The learning media component (95.18%) received a positive evaluation for its suitability to student characteristics, reliability of presentation, interactivity, and ease of use.

Effectiveness of FlipVlab Learning Model

The learning was conducted in the 2025 class of the Bachelor of Science Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret. There are two classes (A and B), each containing 38 and 39 students who have never taken Basic Chemistry courses. Both classes have been tested and have equivalent abilities.

The equivalence of the two classes was tested by comparing their scores on basic chemistry practice questions before the research began. The results showed that Class A scored 48.79 and Class B scored 49.40. Next, the Shapiro-Wilk normality test was conducted, yielding significance values of 0.214 for Class A and 0.360 for Class B. Both had Sig. values > 0.05, indicating that the data from both classes are normally distributed. In Levene's test of homogeneity, the significance value was 0.714 > 0.05, meaning the data are homogeneous. Next, an Independent t-Test was conducted to determine whether there was a difference in the students' practice test scores or their initial understanding of the Basic Chemistry course. The test yielded a significance value of 0.657 > 0.05, indicating that there was no difference between Class A and Class B.

Class A is an experimental class where the FlipVlab learning model is implemented. Class B is a control class where learning followed a conventional instructional format commonly used by lecturers, consisting of lecture-based explanation, structured worksheet exercises, and quizzes. Learning was conducted face-to-face once a week, 3x170 minutes (3 credits), for a total of 8 meetings discussing 5 basic chemistry topics, namely 1) matter and its properties; 2) atomic structure and the periodic table of elements; 3) chemical bonds and molecular structure; 4) stoichiometry; and 5) acids and bases. Of these eight meetings, two involved real laboratory experimentation in both the experimental and control classes, ensuring equivalent access to hands-on laboratory activities across conditions. The steps and activities of the experimental class can be seen in Table 2.

Table 2. Experimental Classroom Learning Activities (FlipVlab)

FlipVlab Syntax	Activities					
	Educators			Students		
	Online Learning in LMS					
Preparing for Learning	Educators through	present digital	material teaching	Students study the	independently material	using

FlipVlab Syntax	Activities	
	Educators	Students
Study the learning materials independently provided by educators online through the LMS. Educators present the material through digital teaching materials embedded in the LMS.	resources integrated into the LMS. Educators use open discussion columns in the LMS if there are questions that need to be asked. Educators answer students' questions through the LMS discussion column.	digital learning resources integrated into the LMS. Students use the discussion column in the LMS if they have any questions.
Collecting Data (Virtual Experiments) Conduct independent experiments online through the virtual laboratory provided. Educators present experimental activities through the virtual laboratory.	Educators present experimental activities through virtual laboratories. Educators ask students about the obstacles to conducting experiments through the LMS discussion column.	Students conduct experiments through a virtual laboratory. Students fill in observation data tables and save them for discussion during offline learning in class. Students provide feedback if they encounter any obstacles while conducting experiments through the LMS discussion column.
Initial Assessment Complete assessment questions to evaluate readiness before entering the classroom (offline).	Educators conduct preliminary evaluations to assess students' readiness before entering offline classes by providing essay questions to be completed online through the LMS.	Students' complete evaluation questions provided online on the LMS.
Offline Learning in the Classroom		
Confirming Data Confirm the research data by conducting another online experiment collaboratively in class. Confirmation of experimental data can also be done by conducting experiments in a real laboratory.	Educators open offline classes and briefly review previous online learning activities. Educators form groups of students to conduct experiments again as confirmation activities. Experiments can be conducted digitally or through hands-on practice in real laboratories.	Students form groups and conduct the experiment again. Students fill in the observation table in groups. Students compare the observation tables from the previous experiment conducted independently with their groups.
Analyse Analyse the results of the experiment by connecting the theory from reliable literature sources such as books, scientific journal articles, etc.	Educators provide Student Worksheets containing questions that help students analyse the data from the experiments they have conducted.	Students work in groups to complete the student worksheets provided by the instructor and analyse the experimental observation data.
Conclude Conclude the investigation results and present them. The presentation can be in the form of	The educator asks students to summarise their observations.	Students summarise their observations.

FlipVlab Syntax	Activities	
	Educators	Students
a report or presentation material displayed in front of the class.	The educator asks students to present their observations in front of the class.	Students present their observations in front of the class.

At the end of the meeting, a summative test (post-test) was conducted by giving 10 essay questions. The results of this evaluation became the basis for testing the effectiveness of the FlipVlab learning model on student learning outcomes or cognitive understanding. The post-test scores can be seen in Table 3.

Table 3. Test scores (Post-test)

Description	Summative Test Score (Post-test)	
	Experimental Class (A)	Control Class (B)
Number of Students (N)	38	39
Average Score (Mean)	72.72	63.40
Standard Deviation	11.49	11.17
Minimum Score	47.40	43.40
Maximum Score	97.40	93.40
Mean Difference	9.32	9.32
Normality Test	Sig. 0.460	Sig. 0.449
Homogeneity Test	Sig. 0.854	
Independent t-Test	Sig. 0.001	
Cohen's d Effect Size Test	0.823	

Table 3 shows the results of the summative test (post-test) for the experimental class (A) and the control class (B). The experimental class obtained an average score of 72.72, while the control class obtained an average score of 63.40. Based on these data, the average score of the experimental class was 9.32 points higher than that of the control class. Shapiro-Wilk tests indicated normal distributions ($p = .460$ and $p = .449$), while Levene's test indicated homogeneity ($p = .854$). Based on Table 3, the post-test mean value had a significance of 0.854. Thus, the Sig. value is > 0.05 , which means the data is declared homogeneous.

Normality and homogeneity tests have been conducted, followed by hypothesis testing using the independent t-Test. This hypothesis test is useful for determining whether there are differences in learning outcomes, cognitive abilities, or understanding of students in Basic Chemistry after applying the FlipVlab learning model. The following hypotheses will be tested:

H_0 : There is no difference in student learning outcomes after applying the FlipVlab learning model to the Basic Chemistry course.

H_1 : There is a difference in student learning outcomes after applying the FlipVlab learning model to the Basic Chemistry course.

Based on these criteria, it can be stated that the treatment in the experimental class had a large effect. This indicates that the FlipVlab learning model substantially improves students' learning outcomes and cognitive abilities in understanding Basic Chemistry concepts. This improvement may be attributed to the structure of the FlipVlab model, which encourages students to engage with learning materials and virtual laboratories before class through the flipped classroom approach, allowing more time for discussion, problem-solving, and conceptual clarification during classroom sessions. In addition, the use of virtual laboratories allows students to visualise abstract chemical processes and conduct repeated experimentation, which strengthens conceptual understanding. The inquiry-oriented learning stages in FlipVlab also promote active knowledge construction, which contributes to deeper learning compared to conventional instruction.

Discussion

The results of this study indicate that the learning model developed for the Basic Chemistry course demonstrates strong validity/feasibility across the instructional design, learning materials, and learning media components, which collectively achieved ratings within the "very good" category

(Table 1). This model was also associated with significantly higher post-test performance in the experimental class compared with the control class ($72.72 > 63.40$; independent t-test, Sig. = 0.001; Cohen's $d = 0.823$), indicating a large effect.

This performance advantage can be explained by specific differences in how instructional time and experimental access were structured between the two classes. Although the control class's teaching plan formally designated Problem-Based Learning, classroom implementation in practice followed a conventional format consisting of lecture-based explanation, structured worksheet exercises, and quizzes across eight sessions, including two sessions of real laboratory experimentation. The FlipVlab class received the same two real laboratory sessions, used specifically for the data-confirmation stage; the key difference lies in the addition of a pre-class virtual laboratory phase, in which students conducted preliminary experiments and formed initial hypotheses before face-to-face instruction. This restructuring shifted face-to-face time in the FlipVlab class away from direct content delivery and toward data confirmation, analysis, and conclusion-drawing, whereas face-to-face time in the control class remained largely allocated to lecture-based explanation. Because both classes had equivalent access to real laboratory experimentation, the observed difference in post-test outcomes is more plausibly attributable to the pre-class virtual laboratory engagement and the restructured use of face-to-face time than to differences in hands-on laboratory access. This interpretation is further supported by the baseline equivalence test conducted prior to the intervention, which indicated no significant difference in students' prior ability between the two classes (Sig. = 0.657), suggesting that the observed post-test difference is more plausibly attributable to the instructional intervention than to pre-existing group differences.

The flipped classroom design embedded in the learning model further strengthens its overall instructional coherence by aligning independent pre-class engagement with structured, inquiry-oriented activities conducted during face-to-face sessions (Shidiq et al., 2020). However, much of this prior evidence compares flipped-classroom instruction against traditional, lecture-based conditions with limited or no laboratory access, making it difficult to isolate whether observed benefits stem from the flipped structure itself or from unequal access to experiential learning. The present findings extend this body of evidence by demonstrating that FlipVlab's advantage persisted even when the control class received equivalent access to real laboratory experimentation, suggesting that the restructuring of instructional time (rather than laboratory access alone) is a meaningful driver of the observed learning gain. From a practical perspective, this model provides lecturers with a structured framework for integrating digital preparation, virtual experimentation, and in-class inquiry activities within a single instructional design. The model also offers a feasible alternative for institutions with limited laboratory facilities by optimising the use of virtual laboratories to complement face-to-face instruction (Salim et al., 2026; Shidiq et al., 2021).

By shifting content acquisition to the pre-class environment, class time can be dedicated to problem-solving exercises, case analyses, and pro-con debates, enabling students to actively apply and refine their conceptual understanding (Shidiq et al., 2019). Moreover, the model's alignment with both virtual laboratory engagement and face-to-face inquiry activities ensures that students transition smoothly between independent exploration and guided collaborative learning. Despite its theoretically anticipated advantages, the implementation of a flipped classroom model introduces important practical considerations and challenges that must be acknowledged within the context of the present study. The transition from traditional lecture-based teaching to a student-centred flipped structure requires a significant pedagogical shift for both instructors and learners, as it demands new patterns of preparation, interaction, and engagement (Larcara, 2015). This shift is directly relevant to the present context, given that the control class in this study followed a lecture-based instructional format. The approach also relies heavily on technology, including pre-recorded instructional materials and online content, which necessitates robust digital infrastructure and equitable access for all students (Lo et al., 2018; Mazlan et al., 2025). Instructor training and support are therefore essential, as educators must be equipped to design and deliver high-quality flipped content while scaffolding students' independent preparation effectively (Long et al., 2017). These factors may also influence implementation success (Chuang et al., 2018; Sandhu et al., 2021).

LIMITATION

This study is subject to several limitations that should be considered when interpreting the findings. The expert judgment instrument used a rating-scale approach rather than a formal content-validity index (e.g., Aiken's V), which may be considered in future instrument development to provide a more standardised measure of inter-rater agreement. This study employed intact classes rather than individually randomised groups, as random assignment was not feasible within the institutional class structure. Although a baseline equivalence test conducted prior to the intervention indicated no significant difference in prior ability between the two classes (Sig. = 0.657), the absence of individual random assignment means that unmeasured pre-existing differences cannot be entirely ruled out. The classes were selected using purposive sampling based on availability rather than random sampling from the target population, which may limit the extent to which the sample represents the broader population of Basic Chemistry students. The control class was formally designated to use Problem-Based Learning, but its actual implementation followed a conventional lecture-based format. This discrepancy between planned and enacted instruction should be considered when interpreting the comparison between the two groups. The research trial was also conducted at only one campus, thereby limiting generalisability to other campuses with different curricula, student characteristics, infrastructure, and other contextual factors.

Several limitations further relate to the scope of implementation and measurement in this study. The FlipVlab learning model has so far been implemented across five topics within the Basic Chemistry course and within a single course; further research is needed to examine its application to other topics and to other science courses that involve laboratory experiments. The study assessed effectiveness only in terms of cognitive learning outcomes; future research should examine other learning outcomes and skills. Finally, a larger-scale field trial involving more students is recommended to strengthen the effectiveness evidence for the FlipVlab learning mode.

CONCLUSIONS

The FlipVlab learning model is designed to facilitate science learning, particularly in Basic Chemistry, in environments where opportunities for laboratory experimentation are limited, with the aim of improving students' learning performance. This model integrates the Scientific Inquiry learning approach with the flipped classroom strategy and uses a virtual laboratory as an experimental support medium. The FlipVlab model incorporates systematic instructional syntax (preparing to learn, collecting data, conducting initial evaluation, confirming data, analysing, and concluding), supported by a defined social system, reaction principles, support system, and intended instructional impacts. The feasibility of the FlipVlab learning model was assessed by nine experts and received average scores of 95.14 for instructional design, 93.65 for learning materials, and 95.18 for learning media, all falling within the "very good" category, indicating that the model is feasible for classroom implementation. The developed model was subsequently implemented and evaluated through a quasi-experimental field trial. A baseline equivalence test indicated no significant difference in prior ability between the experimental and control classes (Sig. = 0.657), supporting the comparability of the two groups prior to treatment. An independent samples t-test showed a significant difference in post-test performance between the classes (Sig. = 0.001 < 0.05), and a Cohen's d of 0.823 indicated a large effect size. These findings indicate that, within the sampled classes, FlipVlab was associated with significantly higher Basic Chemistry learning outcomes compared with a conventional instructional approach. However, the design limitations outlined above should be considered when interpreting the generalisability of these results.

AUTHOR CONTRIBUTION

BA contributed to conceptualisation, methodology, investigation, data curation, formal analysis, and writing of the original draft. KK contributed to validation, supervision, methodology review, and project administration. IH contributed to validation, supervision, methodology review, and manuscript review and editing.

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