Developing a BIM Modeling Instructional Model Based on Flipped Classroom and Collaborative Learning for Architectural Engineering Students

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Abstract

This study aims to present a process for developing and validating of a BIM modeling instructional model by using expert judgment and a pilot study. This article showed the results of two phases. Phase one, questionnaires (n=95) and semi-structured interviews (n=15) were used to identify instructional problems and learning preferences. The results of phase one and review literatures were used to develop the instructional model. Results from the survey indicated strong student preferences for pre-class learning materials, collaborative tasks, and real-world project integration. Phase two, a BIM modeling instructional model integrating flipped classroom and collaborative learning approaches was developed to enhance the modeling skills of Chinese architectural engineering students. The model included principles, objectives, learning steps, teacher and student roles, and assessment methods. Expert validation (N=5) using a 5-point Likert scale showed high to highest level of all six components as 4.24,4.36,4.64,4.44,4.24,4.30 respectively. The teaching steps includes 5 steps aligned with pre-class self-learning, in-class team-based modeling tasks, and continuous formative assessment. Seven lesson plans based on this framework were developed and validated by five experts. Five experts evaluated the lesson plans using the established criteria and consistently rated them at the high to highest levels. Then 45 students were recruited to conduct the pilot study to consider the model feasibility. Students showed a positive attitude towards learning. Content, activities, assessment methods, tools in each lessons were revised to align with students' feedback and identifying recurring issues. These findings provide a pedagogically sound framework for enhancing BIM modeling competence in higher education.

Keywords: BIM modeling, flipped classroom, collaborative learning, instructional model, construction engineering education

1. Introduction

1.1 Background of the Study

In recent years, the global construction industry has been undergoing profound transformation driven by digitalization and intelligent technologies. At the center of this transformation, Building Information Modeling (BIM) has become a key driver of industry upgrading. BIM is not only regarded as an essential tool to improve project efficiency and quality but is also widely recognized as a core competence required for future construction engineering professionals (Charles, 2011). Therefore, governments, industry enterprises, and educational institutions all place strategic importance on the cultivation of BIM skills.

In China, the Ministry of Education officially included BIM professionals in the national occupational classification system, designating it as an independent professional category. This policy reflects the government's recognition of the strategic role of BIM in enhancing the informatization and modernization of the construction industry (Ministry of

Education, 2012). Furthermore, the “14th Five-Year Plan for the Development of the Construction Industry” explicitly calls for the accelerated adoption of BIM across the sector, promoting intelligent construction and digital collaborative design, developing standardized frameworks, and strengthening industrial internet platforms to enhance overall efficiency and international competitiveness (Ministry of Housing and Urban-Rural Development, 2022).

More broadly, with the integration of information technology, renewable energy, and intelligent manufacturing, the world is rapidly entering the so-called “post-carbon era.” This industrial transformation, characterized by digitalization, greening, and intelligence, is often described as the “Third Industrial Revolution” (Yang, 2023). Within this context, BIM has emerged as a core technology of construction informatization, enabling refined lifecycle management of buildings. Through three-dimensional modeling, parametric design, and cross-disciplinary collaboration, BIM not only improves engineering efficiency but also supports the industry’s sustainable development.

The development of BIM in China has been remarkably rapid. Reports indicate that the market size grew from approximately 40.5 billion RMB in 2016 to 119.1 billion RMB in 2020, and further expanded to 360 billion RMB by 2022, with a compound annual growth rate of 30%. The market is expected to continue this upward trend in the coming years (Zeng, 2024; Zhou & Zhou, 2024). According to a report by Zhiyan Consulting, the BIM industry in China reached 99.5 billion RMB in 2022, of which application services accounted for 78.3% and system operation and maintenance accounted for 21.7% (Zhiyan Consulting, 2024). These figures demonstrate the dual driving forces of government policy and market demand, while also highlighting the urgent need to strengthen BIM education in talent cultivation.

In the field of education, how to effectively cultivate students’ BIM modeling competence has become an important task for colleges and application-oriented universities. However, current teaching practices remain insufficient. Traditional classrooms are mainly teacher-centered, leaving limited time for students’ independent exploration and hands-on practice. Due to the complexity and steep learning curve of BIM software (e.g., Revit), students often find it difficult to master key skills within limited course hours, leading to weak operational capabilities and a lack of confidence in solving practical problems (Li et al., 2020).

To address this issue, the concepts of flipped classroom and collaborative learning have been gradually introduced into engineering education. The flipped classroom emphasizes pre-class self-study through videos and online resources, while class time focuses on case discussions, task-driven activities, and problem-solving to achieve student-centered deep learning (Bergmann & Sams, 2012). Collaborative learning, rooted in Johnson and Johnson’s cooperative learning theory, stresses group collaboration, role division, and shared responsibility to improve students’ motivation and problem-solving ability (Johnson & Johnson, 1994). These two approaches align well with BIM education, which inherently requires cross-disciplinary collaboration and teamwork.

In practical teaching, combining flipped classroom with collaborative learning has shown significant advantages. Before class, students engage in self-learning of BIM theories and software operation via MOOCs, Rain Classroom, and social media platforms. During class, teachers guide students through modeling practices, group projects, and case-based discussions to simulate real engineering scenarios. After class, group assignments and individual reflections further consolidate learning (Zheng, 2016; Song, 2024). This “three-in-one” teaching model not only strengthens students’ modeling skills but also cultivates teamwork, communication, and project coordination abilities.

Based on the analysis of architectural engineering students’ BIM learning status, this study proposes the development of a BIM modeling instructional model integrating flipped classroom and collaborative learning approaches to enhance students’ modeling skills and teamwork abilities. Effective implementation of this teaching model can cultivate learners with stronger practical skills, problem-solving abilities, and adaptability to engineering practice.

1.2 Purpose of the Study

To develop a BIM modeling instructional model that integrates flipped classroom and collaborative learning to enhance the BIM modeling abilities of architectural engineering students.

1.3 Scope and Limitations of the Study

This study was carried out in two main phases. In the first phase, data were gathered through surveys completed by subject-area instructors and students. The surveys used a 5-point Likert scale, and the quantitative results are reported as overall mean scores. At the same time, qualitative responses were collected to capture students’ perspectives and needs regarding the development of a new instructional model.

The second phase focused on the iterative development of this new instructional model based on flipped classroom and collaborative learning. The process began with the conceptualization of six core components, which were then submitted for evaluation by five experts. Following revisions based on the experts' recommendations, a set of seven lessons was created. These lessons also underwent an expert review for suitability by the same panel. After completing these revisions, the lessons were implemented with one class of student in a pilot study. The aim of this pilot was not to evaluate the effectiveness of the instructional model, but to determine its feasibility and practicality in a real classroom context. The results were then used to adjust each lesson to ensure appropriate pacing and alignment with students' skill levels. These refined materials will be carried forward into Phase 3 of the research, which will be reported in a separate article.

2. Literature Review

2.1 Instructional Model

An instructional model is essentially a guide for creating effective teaching. It provides a clear framework that helps teachers plan and design their lessons. This framework includes proven principles and strategies to help organize the subject matter and select the best activities to support student learning. It is a systematic process, based on scientific research that aims to make instruction reliable and efficient. By following a model, educators can ensure that all learning activities are purposeful and that the instruction helps students achieve their learning goals (Gagné, 2005; Jonassen & Land, 2012; Morrison, Ross, Kemp, & Kalman, 2013).

Key components of an instructional model include the instructional principles, which are the overarching philosophies or theories guiding the learning process, and the learning objectives, which define what students should know or be able to do after instruction. Other common components often integrated into these models are learning content, instructional processes (or activities), roles of instructor and leaners, Teaching media and resources, and assessment and evaluation methods to measure learning effectiveness. An effective instructional model is built from several key parts that must all work together smoothly. At its core, a model has guided principles or a teaching philosophy. It also includes clear learning objectives, which state what students are expected to achieve. The design outlines the specific methods and activities used for teaching, as well as the subject content to be learned. A key idea is that the focus should be on improving the learner's performance and skills, rather than just covering a list of topics. Finally, the model must have a plan for evaluation to measure whether students have successfully met the learning objectives (Anchunda & Kaewurai, 2021).

2.2 Application of Flipped Classroom in BIM Education

2.2.1 Theoretical Basis

The flipped classroom is a student-centered, technology-supported pedagogy that emphasizes “pre-class acquisition of knowledge and in-class internalization and application.” Students engage with videos, micro-lectures, and readings before class, reserving classroom time for discussion, practice, and problem-solving (Thammasarot, Sanrattana & Phrasrivajiravati, 2024). This approach aligns with Mazur’s (1997) peer instruction concept, which emphasizes interaction and co-construction of knowledge. Talbert (2017) notes that flipped classrooms offer flexibility and adaptability, supporting personalized learning and deeper understanding, while Brame (2013) underscores the importance of high-quality pre-class materials and effective classroom interaction for success. In Chinese BIM education, flipped classrooms address the lack of hands-on practice by providing students with more opportunities for modeling exercises and problem-based discussions.

2.2.2 Instructional Components

Flipped classroom instruction typically comprises three elements: (1) Pre-Class Learning: Independent study through videos, micro-lectures, and textbooks to acquire foundational knowledge (Khan, 2012). (2) In-Class Activities: Engaging students in higher-order thinking tasks, including discussions, case studies, and BIM modeling practice (Bishop & Verleger, 2013). (3) Feedback and Support: Instructor guidance to resolve challenges and deepen comprehension (Tucker, 2012).

2.3 Collaborative Learning Theory and BIM Education

Collaborative learning emphasizes small-group cooperation and active interaction for knowledge construction (Siriwattana & Sanrattana, 2023). Its theoretical foundation lies in Vygotsky’s social constructivism, particularly the “zone of proximal development,” which posits that cognitive development occurs through social interaction (Vygotsky, 1978). Research indicates that collaborative learning enhances critical thinking, communication, and problem-solving skills (Slavin, 1996). In BIM education, where modeling processes involve multiple roles—architecture, structure, MEP—collaborative learning strengthens teamwork awareness and simulates real project scenarios, improving model quality and efficiency (Cheng, 2016).

Considering the current state of Chinese BIM education, integrating flipped classroom and collaborative learning addresses the limitations of traditional instruction, including insufficient practice, weak collaboration, and theory-practice gaps. This theoretical and practical foundation directly informs the development of the present BIM modeling instructional model, which employs systematic teaching steps, clearly defined teacher-student roles, and multi-dimensional assessment to enhance students' integrated modeling competence and collaborative capabilities.

3. Method

This study was conducted in two phases. The first phase aimed to investigate the current status of BIM learning and instructional needs of architectural engineering students, while the second phase focused on developing and validating an instructional model that integrates flipped classroom and collaborative learning approaches for BIM modeling.

Phase I: Investigation of the Basic Information of the Teaching Model

3.1 Informants

In this phase, data were gathered using questionnaires and semi-structured interview methods. The questionnaire was administered to 95 sophomore and junior students from the School of Architecture at Guangzhou Huashang Vocational College. Its purpose was to examine students' current experiences with BIM learning, their learning needs, and their attitudes toward flipped classroom and collaborative learning approaches. In addition, semi-structured interviews were conducted with 15 participants, including five architecture students, five faculty members, and five external BIM specialists, to gain deeper insights into existing teaching practices.

3.2 Research Instruments

This phase used a questionnaire survey and a semi-structured interview protocol as the main research instruments. The questionnaire was developed from an extensive review of the literature and included three key components including demographic information, the current status and needs related to BIM modeling competence, and students' evaluations of instructional methods. It used a five-point Likert scale and contained both rating items and open-ended questions. The 40 rating items were organized into seven sections: (1) classroom learning styles, (2) pre-class independent learning, (3) group collaboration during class, (4) use of online learning tools, (5) perceived improvement in learning outcomes, (6) instructional support needs, and (7) overall evaluation of teaching approaches.

The content validity of the questionnaire was assessed by five experts using the Content Validity Index (CVI). All items showed item-level CVI (I-CVI) values between 0.8 and 1.0, which indicates acceptable content validity. The overall scale-level CVI using the average method (S-CVI/Ave) was 0.97, showing that the questionnaire covered the intended research constructs well. Content Validity Ratio (CVR) was also used to assess whether each item was essential, and every item received a value of at least 0.6, which is higher than the recommended minimum of 0.49. Inter-rater reliability (IRR) was checked using the modified Kappa statistic, and all items reached coefficients of 0.76 or higher, demonstrating strong agreement among the experts. The internal consistency reliability of the questionnaire was confirmed with Cronbach's alpha values of 0.6 or above. The finalized questionnaire was then pilot tested with 45 third-year students from the School of Architecture at Guangzhou Huashang Vocational College.

The semi-structured interview protocol was developed through a systematic process that included identifying learning principles, clarifying the interview content, drafting the questions, obtaining review from the supervisor, and incorporating feedback from experts before making revisions. The validity of the interview questions was confirmed using CVI, CVR, and IRR. The results showed a scale-level CVI of 0.98, and all item-level CVI values were 0.8 or higher, indicating that the questions reflected the research objectives well. All items also reached a CVR value of at least 0.6, and 60 items received a CVR of 1.0, showing that they were considered essential. Inter-rater reliability (IRR) tests produced Kappa values of 0.76 or higher, demonstrating strong agreement among raters. These findings confirmed that the interview protocol was scientifically robust and could offer reliable insights for developing a BIM instructional model that incorporates flipped classroom and collaborative learning.

3.3 Data Analysis

The research team distributed questionnaires to 95 students and collected semi-structured interview data from 15 participants, including experts, teachers, and students. The questionnaires were used to obtain quantitative information, while the interviews complemented them with qualitative insights, providing a comprehensive understanding of students' BIM learning status and instructional needs.

The responses from the rating-scale questionnaire were interpreted using the classification adapted from Sugiyono (2017), as presented in Table 1. For the qualitative interview data, the analysis involved identifying relevant information and grouping it into meaningful categories. The content analysis followed four steps. First, all interviews were transcribed word for word. Second, open coding was used to identify important concepts. Third, axial coding was applied to bring related ideas together into sub-themes. Finally, selective coding was used to form the main categories. Because the interview instrument had strong validity and reliability, it provided rich and detailed qualitative insights. These findings supported the quantitative results from the questionnaire and helped highlight the key classroom management factors that support the development of BIM modeling competence in architectural engineering students.

Table 1. Five-point Likert Rating and Interpretation

Positive Statement	Score	Negative Statement	Score	Rating	Interpretation
Strongly Agree	5	Strongly Agree	1	4.51 – 5.00	Strongly Agree
Agree	4	Agree	2	3.51 – 4.50	Agree
Neutral	3	Neutral	3	2.51 – 3.50	Neutral
Disagree	2	Disagree	4	1.51 – 2.50	Disagree
Strongly Disagree	1	Strongly Disagree	5	1.00 – 1.50	Strongly Disagree

Phase II: Instructional Model Development and Validation

The second phase included two main parts. The first part focused on developing the instructional model. In this step, the researchers combined flipped classroom methods with collaborative learning to create an instructional model that could strengthen BIM modeling competence among architectural engineering students. The second part involved planning and validating the lesson based on the instructional model. The researchers designed lesson plans and carried out a pilot implementation to examine how well the model and the lesson plans could be applied in practice and how effective they might be.

3.4 Instructional Model Development

3.4.1 Informants

The development and evaluation of the instructional model were carried out by five experts at the doctoral level. Four of them were specialists in curriculum and instruction, and one was an expert in educational statistics. All experts had substantial experience in their respective fields.

3.4.2 Research Instruments

To construct the instructional model integrating flipped classroom and collaborative learning approaches, the research team first extracted key components from literature reviews and exemplary case studies. The development process involved reviewing the literature, integrating the two teaching approaches, and drafting the model. The draft included the background, theoretical framework, guiding principles, objectives, instructional steps, roles of teachers and students, learning resources, and the assessment plan. The draft was then reviewed by experts. They rated the model using a five-point Likert scale, and the average scores were higher than 4.0, showing that the design was appropriate. The consistency of expert judgments was examined using the intra-class correlation coefficient (ICC), which ranged from 0.78 to 0.82 for different components. These values indicated strong agreement among the experts and supported the reliability of the model structure. After receiving feedback, the research team revised the model, creating a solid basis for the next stage of course development.

3.4.3 Data Analysis

The responses from the rating questionnaire were interpreted using the classification adapted from Sugiyono (2017). The contents of the model served as the criteria for evaluating how appropriate the instructional model was. Data from the draft evaluation form were analyzed by calculating mean scores along with their assigned weightings. The criteria divided the level of appropriateness into five groups. The highest level corresponded to mean scores from 4.50 to 5.00. The high level covered scores from 3.50 to 4.49. The medium level covered scores from 2.50 to 3.49. The low level covered scores from 1.50 to 2.49. The lowest level covered scores from 1.00 to 1.49. This system made it possible to convert qualitative feedback from the questionnaire into numerical data for statistical analysis, allowing for an objective and systematic evaluation of the instructional model.

3.5 Course Planning and Validation

3.5.1 Pilot Group

The pilot study involved 45 students from the School of Architectural Engineering at Guangzhou Huashang Vocational College, selected through cluster random sampling. Five experts at the doctoral level also took part in the evaluation. Four of them specialized in curriculum and instruction, and one specialized in educational statistics. All experts had a minimum of five years of experience in their field.

3.5.2 Research Instruments

This phase focused on developing an instructional model and lesson plans to strengthen BIM modeling competence by integrating flipped classroom and collaborative learning. The research team began by reviewing relevant literature to identify the essential components needed for the course and drafted the initial lesson plan. After preliminary supervision and revisions, an evaluation rubric was prepared using criteria that emphasized the appropriateness of the course, the consistency of its content, and its practical usefulness. The course plan and the evaluation rubric were then reviewed by five experts at the doctoral level. These experts rated the feasibility of the course in four areas, which were appropriateness, accuracy of content coverage, expected benefits, and flexibility, using a five-point Likert scale. The average scores were higher than 3.56, which placed the course in the high category. Intra-class correlation coefficients (ICCs) were calculated to check how consistently the experts rated the course, and all values were above 0.79, with most above 0.90, showing good to excellent agreement. After this review, the course was pilot tested with the 45 architectural engineering students, and their feedback was used to make further improvements.

3.5.3 Data Analysis

Responses to the rating-scale questionnaire were interpreted by adapting Sugiyono (2017). Quantitative data (expert ratings) were summarized using means and standard deviations, while qualitative data (expert comments and student reflections) were analyzed through content analysis. These findings collectively provided a solid foundation for large-scale implementation and further evaluation of the instructional model's effectiveness.

4. Results

To evaluate the current situation and development needs related to BIM technology skills among architecture students, this study examined the differences in how in-service architects and students understand the core competencies required for BIM. This comparison helps identify ways to improve the existing training system for future professionals.

The questionnaire data were collected from 95 second- and third-year students in the School of Architectural Engineering. Participation was voluntary, and the survey used the BIM Capability Assessment Questionnaire for Building Informatization Talents which covers core competency dimensions such as BIM theoretical knowledge and BIM software operation.

4.1 Questionnaire Results

A total of 95 construction engineering students from Guangzhou Huashang College participated in the questionnaire survey, which covered six dimensions: classroom learning style, pre-class self-directed learning, group collaborative practice, online learning tools, perception of learning enhancement, and teaching support needs. To ensure the reliability of the instrument, Cronbach's Alpha coefficient was applied to test internal consistency ($\alpha > 0.6$), and content validity was verified through expert review. The values of each dimension were calculated.

This study used a BIM course questionnaire that showed high reliability, with a Cronbach's alpha of 0.813. The questionnaire applied a five-point Likert scale, where a higher score reflected stronger agreement. The average scores for the six areas were as follows. Classroom learning style received a mean score of 3.77. Pre-class self-directed learning received 3.56. Group collaborative practice received 3.85. Online learning tools received 3.44. Perception of learning enhancement received 4.10. Teaching support needs received 3.90. The results show that students have a strong preference for innovative learning models such as the flipped classroom and collaborative learning, with their responses ranging from a lower quartile of 1.95 (Q1) to an upper quartile of 4.47 (Q3). They place high importance on preparing before class, with a mean score of 4.47 (Q14), and they also demonstrate active self-directed learning, with a score of 4.23 (Q13). Students feel that working in groups helps them improve their skills, with scores of 4.49 (Q20) and 4.42 (Q23), and they recognize the usefulness of online learning tools, which received scores of 4.32 (Q24) and 4.41(Q27). Most importantly, students generally believe that their learning outcomes have improved, as shown by scores of 4.41 (Q30) and 4.47 (Q31). At the same time, they express a clear need for stronger teaching support. They would like more detailed demonstrations of the software, clearer explanations of tasks, and more explicit learning standards, reflected in scores of 4.34 (Q36), 4.28(Q37), and 4.47(Q40). These results are presented in Figure 1.

Figure 1. Bar Chart of the Six - Dimensional Questionnaire

Based on these findings, instructional optimization should focus on three main areas. First, students need pre-class materials that clearly explain the learning goals. Second, the course should include realistic group tasks supported by better software demonstrations and opportunities for peer feedback during class. Third, the assessment system should shift toward ongoing evaluation, with stronger guidance for group work and a well-organized collection of learning resources. These improvements will help strengthen students' core BIM skills and raise the overall quality of teaching.

In conclusion, across the above dimensions, students show a generally positive attitude toward the flipped classroom and collaborative learning model. They believe that pre-class preparation, teamwork, and case-based analysis effectively improve their BIM modeling abilities, while also expecting teachers to provide clearer demonstrations, task guidance, and learning standards. This indicates that future instructional design should balance "self-directed learning – collaborative practice – teacher support."

4.2 Semi-Structured Results

The semi-structured interviews were conducted with five architecture students from Chinese universities, five teachers from the school (two were senior educators and three were senior instructors specializing in BIM), and five external experts in the field of BIM. The purpose of the interviews was to understand how the current teaching model influences the development of BIM competencies and to gather suggestions for improving future instructional approaches.

According to the comprehensive compilation of interviews, it can be found that students have a positive attitude towards flipped classroom and collaborative learning mode in actual teaching experience, not only performing well in self-learning, self-discipline and technical adaptation, but also achieving significant growth in teamwork, problem solving and professional skills improvement. At the same time, experts generally believe that this teaching mode meets the high requirements of BIM courses for practical ability and teamwork, and helps to improve students' modeling efficiency and engineering thinking. In order to further optimize the teaching effect, the research team summarized the key insights and put forward corresponding feasible suggestions, which provided a strong basis for the improvement and promotion of the model.

Table 2. Comprehensive Collation of Interviews

Key Insights	Actionable Recommendations
1. Students are more inclined to take the initiative to learn, oppose the traditional "teacher-oriented teaching" model, and generally accept flipped classrooms	Teachers should provide structured self-study resources and clear learning goals, and design problem-oriented pre-class tasks to stimulate students' learning initiative
2. Students highly recognize the effect of collaborative learning, which can promote understanding, improve problem-solving ability and normative awareness	In teaching, group cooperation tasks should be strengthened, the division of tasks should be clarified, and group discussions and peer evaluation should be added to enhance interaction
3. Students have strong pre-class self-learning ability and initiative, but hope that the task goals will be clearer and clearer	Teachers should provide detailed task descriptions and standards, and support problem sheets to guide students to focus on difficulties and prepare for class
4. Students can effectively use online tools such as video conferencing and cloud collaboration, and do not exclude online collaboration	Continuously train students to use digital tools and integrate online platform resources for group tasks, learning tracking, and data sharing
5. The current teaching mode significantly improves students' abilities in theory, software operation and teamwork	Continue to use "flip + collaboration" hybrid teaching, strengthen practical task design and stage goal setting to promote gradual improvement
6. Students want teachers to provide more software demonstrations and industry cases, and think that the current resources are still insufficient	Teachers should enrich teaching resources, especially industry cases and software operation videos, and clarify the evaluation criteria for self-learning content

4.3 Development of an Instructional Model

4.3.1 Drafting the Instructional Model

On this basis, a preliminary draft of the instructional model was developed, including seven key components: the basic principles of the instructional model, instructional objectives, learning processes, teacher and student roles, learning resources and media, and assessment methods.

4.3.2 Principles of the Instructional Model

1) Establishing Key Principles of the Flipped Classroom

The flipped classroom follows constructivist-driven knowledge construction, allowing students to actively generate new knowledge by connecting prior knowledge through pre-class inquiry and in-class interaction in social and contextual settings (Bransford, Brown, & Cocking, 2000). It empowers self-regulated learning, enabling students to plan their learning paths using pre-class resources and tasks, with goals and feedback reinforcing autonomous learning abilities (Zimmerman, 2002). Scaffolds are provided according to the zone of proximal development, where peer assistance and teacher guidance help students surpass current levels and achieve higher competencies (Vygotsky, 1978). Connectivism adapts the model to digital ecosystems, leveraging online resources and platforms to expand knowledge and enhance digital literacy (Siemens, 2005). Multiple theories collaboratively reconstruct the teaching and learning paradigm.

Table 3. Foundational Theories of the Flipped Classroom

Constructivist Learning Theory	Self-Organized Learning Theory	Zone of Proximal Development Theory	Connectivism Learning Theory
C1: Actively construct knowledge; C2: Learning occurs in context; C3: Social interaction is central to learning; C4: Learners' prior knowledge shapes new learning	S1: Learners can autonomously plan and control their learning; S2: Learning is a self-regulated process; S3: Goals and feedback enhance regulation ability	Z1: Learning potential extends beyond current level; Z2: Instruction should provide scaffolds for support; Z3: Interaction supports development	N1: Knowledge exists in networks; N2: Learning is the process of connecting information nodes; N3: Digital literacy affects learning outcomes

By integrating the main ideas from the four theories and summarizing their essential concepts, the principles of the flipped classroom were identified. These principles are presented in Table 3.

Table 4. Flipped Classroom Principle

Combined Theoretical Constructs	Flipped Classroom Principle (FC)
C1 + C2 + S1 + N2 + C4	FC-1: Facilitate Knowledge Construction through Pre-Class Self-Learning and In-Class Practice. Students independently construct knowledge using videos and materials before class, then deepen understanding through discussions and hands-on tasks in contextualized classroom activities. This emphasizes cognitive development through experience and interaction.
S1 + S2 + S3 + Z3 + C2	FC-2: Personalized Learning Pathways Based on Goal-Setting and Self-Regulation. Teachers define clear learning objectives and criteria, while students continually adjust strategies based on feedback, forming individualized learning rhythms and mastery of content.
Z1 + Z2 + S2 + C4	FC-3: Promote Competency Development through Teacher Support and Interactive Challenges. Teachers design challenging tasks and provide timely scaffolding during class, helping students bridge their current abilities and achieve higher levels of competence.
N1 + N2 + N3 + C3 + Z3	FC-4: Foster Deep Learning through Digital Connectivity and Group Collaboration. Students establish connections to information through videos, platforms, and digital resources, while in-class group collaboration and project-based tasks integrate and transfer learning, enhancing digital literacy and responsibility.

2) Formulating the Key Principles of Collaborative Learning

Collaborative learning, as a critical strategy to promote students' deep understanding, social interaction skills, and critical thinking, is theoretically supported across multiple dimensions. Based on social interdependence theory, complementary roles, shared goals, and collective incentives strengthen positive individual interactions and goal interdependence within groups, ensuring effective collaboration (Johnson & Johnson, 2009). At the same time, drawing on social constructivist theory, students internalize knowledge and engage in joint construction through social interactions such as group discussions and debates, achieving higher-level understanding. Additionally, by integrating cognitive development theories, diverse interactions are leveraged to stimulate cognitive growth, ultimately providing a solid foundation for instructional activity design (Vygotsky, 1978).

Table 5. Theoretical Foundations of Collaborative Learning

Social Interdependence Theory	Social Constructivist Theory	Sociocultural Theory & Zone of Proximal Development (Vygotsky)	Cognitive Development Theory	Structure-Process-Outcome Theory (Watson & Johnson)
D1: Goal structures influence group interaction; D2: Individual success depends on team success; D3: Positive interdependence among group members is required	S1: Knowledge is constructed through social interaction; S2:Students collaboratively construct meaning	L1: Cognitive development is socially mediated; L2: ZPD – learners perform tasks under guidance; L3: Scaffolding by knowledgeable others facilitates progress	C1: Cognitive conflict promotes thinking development; C2:Peer interaction fosters higher-order thinking	SPO1:Task structure determines interaction process; SPO2:Effective structure promotes collaborative interaction and positive outcomes

By integrating the key concepts of the five theories and synthesizing their core ideas, the principles of collaborative learning are derived.

Table 6. Principles of a Collaborative Learning Approach

Model principle	Principles of a collaborative learning approach
D1 + D2 + D3 + SPO1	CL-1: Goal Interdependence and Motivation Principle. Learning objectives must be designed for groups to accomplish collectively, ensuring that individual success depends on team success, thereby stimulating active cooperative motivation.
S1 + S2 + L1	CL-2: Social Construction and Shared Meaning Principle. Students collaboratively construct knowledge through social interaction, where meaning is continuously negotiated and formed during collaboration, making learning more profound and relevant.
L1 + L2 + L3	CL-3: Scaffolded Guidance and Progressive Development Principle. Learning is guided through tasks within the "Zone of Proximal Development," supported by scaffolding from more experienced individuals, helping learners achieve growth beyond their current level.
C1 + C2 + S2	CL-4: Cognitive Conflict and Multiple Perspectives Principle. Design challenging group tasks to stimulate students' critical thinking and understanding through debate, cognitive conflict, and negotiation.
SPO1 + SPO2	CL-5: Structure-Driven Process Optimization Principle. Effective collaborative learning relies on rational structural arrangements (e.g., division of labor, goals, resources) to facilitate positive interaction processes and ultimately achieve productive learning outcomes.

3) Establishing the Instructional Principles Integrating Flipped Classroom and Collaborative Learning

The flipped classroom and collaborative learning emphasize students' pre-class self-directed knowledge construction and in-class understanding through interaction and group collaboration. Integrating these two approaches balances the advantages of autonomous learning and teamwork, creating a learning environment centered on task-driven activities, interactive inquiry, and competency development. Based on the objectives of this study, the core principles of both the flipped classroom and collaborative learning were considered to construct the principles of the new instructional model, as follows.

Table 7. Instructional Principles of a Flipped Classroom and Collaborative Learning Model for BIM

Model Principles	Instructional Principles
FC-1 + FC-4 + CL-2	Principle 1: Pre-class study and in-class collaboration. Learn basics pre-class, deepen via group discussion.
FC-2 + CL-1 + CL-3	Principle 2: Individual goals and team tasks. Set personal goals, complete group modeling, improve via collaboration.
FC-3 + CL-4 + CL-5	Principle 3: Guided conflict and tool-based resolution. Design challenges, guide group discussion on solutions.
FC-4 + CL-1 + CL-5	Principle 4: Technology support and goal interdependence. Use platforms for group work, share/feedback in real time.
FC-1 + FC-2 + CL-2 + CL-4	Principle 5: Self-directed inquiry and consensus building. Explore pre-class, discuss solutions to reach shared understanding.
FC-3 + CL-5	Principle 6: Guided collaborative problem-solving. Design authentic tasks, guide groups to address modeling challenges.

4.3.3 Instructional Model Objectives

To establish the objectives of the instructional model, the researchers analyzed the model principles in relation to students' BIM modeling competencies.

Table 8. Learning Objectives Mapping in the Flipped Classroom and Collaborative Learning BIM Model

Model Principles	Model Objectives
Principle1 + Principle5 + B1 + B2	Objective 1: Develop students' autonomous knowledge construction and negotiation skills, enabling mastery of basic concepts and family modeling, while enhancing cognition through collaboration.
Principle2 + Principle4 + B2 + B3	Objective 2: Enable students to complete team modeling tasks on a technical platform, achieving coordination from family components to project-level models.
Principle3 + B3	Objective 3: Enhance students' ability to identify and resolve modeling conflicts, improving comprehensive skills in tool-based project operations.
Principle4 + Principle6 + B2 + B3	Objective 4: Facilitate completion of authentic tasks in family and project modeling, collaboratively adjusting parameters and integrating models.
Principle5 + Principle6 + B1 + B3	Objective 5: Promote application of theoretical knowledge to complex modeling scenarios and foster strategy alignment through group communication.

4.3.4 Instructional Model Steps and Corresponding Teacher and Student Roles

Following the discussion of the theoretical framework and core principles of the flipped classroom and collaborative learning instructional model, this section further maps the learning objectives to specific instructional steps. The table below illustrates each step of the teaching model and clarifies the roles of teachers and students, providing a foundation for subsequent implementation and effectiveness analysis.

Table 9. Mapping Learning Objectives to Instructional Steps

Learning Objective	Instructional Step	Teaching Activities	Teacher's Role	Student's Role	Stage
Objective1: Develop autonomous knowledge construction and negotiation	Step 1: Pre-class preparation & knowledge acquisition	Provide micro-lectures and learning resources	Facilitate preview, clarify concepts	Complete preview tasks, record questions	Before class
Objective 2: Coordinate individual goals and team tasks on technical platforms	Step2: Task decomposition & role division	Assign tasks and clarify evaluation criteria	Guide role assignment, explain group goals	Take roles, plan team workflow	In class
Objective 3: Identify conflicts and solve problems using tools	Step 3: Layered challenges & conflict discussion	Design challenges and discussion prompts	Scaffold problem-solving, monitor debates	Discuss conflicts, propose modeling solutions	In class
Objective 4: Complete authentic project modeling and integration	Step4: Collaborative modeling & presentation	Set up project scenarios, supervise process	Support collaboration, provide feedback	Execute modeling tasks, present results	In class
Objective 5: Apply theory to complex scenarios and form unified strategies	Step5: Reflection & consolidation	Facilitate reflection and organize presentations	Summarize experiences, highlight strategies	Reflect, consolidate learning, share insights	After class

The teaching model developed in this study presents a structured integration of Flipped Classroom (FC) and Collaborative Learning (CL) tailored to the enhancement of BIM modeling competencies. Grounded in established educational theories, the model systematically connects six instructional principles with five core learning objectives, ensuring a coherent progression from pre-class preparation to in-class collaboration and post-class reflection. It emphasizes the interplay between individual self-directed learning, team-based modeling tasks, and guided problem-solving, supported by digital platforms to facilitate real-time interaction and knowledge sharing. By explicitly mapping principles to objectives and instructional steps, the model clarifies the roles of teachers and students at each stage, promoting autonomous knowledge construction, practical application of theoretical concepts, and collaborative resolution of complex modeling challenges. Overall, the model provides a comprehensive, task-oriented framework that cultivates both individual technical skills and collaborative competencies essential for effective BIM practice.

4.4 Learning Media and Resources

Based on the preliminary survey and interview results, and considering practical conditions, the learning media and resources required for each instructional step include: (1) online learning platforms and course materials, (2) information retrieval and analysis tools, (3) collaboration and team management tools, (4) hands-on and experimental tools, and (5) assessment and presentation tools.

4.5 Assessment of Students' BIM Modeling Ability

Based on the above research, the ability to study BIM modeling can be summarized into three points: 1) Theoretical knowledge comprehension ability. 2) Family modeling ability. 3) Project modeling and parameter collaboration ability.

4.6 Validating of the Instructional Model of Expert Verification

To ensure the scientific rigor and applicability of the developed instructional model, five field experts reviewed its six core components: principles, objectives, learning steps, teacher role, learner role, and assessment method. Each item was rated on a five-point Likert scale, and the intra-group correlation coefficient (ICC) was calculated to examine consistency.

The evaluation results showed that the average scores of all components were between 4.00 and 5.00, and the ICC values were between 0.78 and 0.82. These values meet the reliability standards proposed by Koo and Li (2016). The teaching principles and learning steps both reached an ICC of 0.82, which reflects strong agreement and a well-structured sequence. The objectives reached an ICC of 0.80 with a ninety-six percent agreement rate, showing that the goals were clear and appropriate. The teacher role, which was mostly rated as excellent, had an ICC of 0.78. The learner role reached an ICC of 0.80, indicating that it was well aligned with the teaching goals. The assessment method also showed strong consistency, with an ICC of 0.82.

Overall, the expert evaluation confirmed that the instructional model demonstrates high consistency, good reliability, and strong content validity. These results indicate that the model has a reasonable structure and can effectively guide the teaching of BIM modeling skills.

Results from quality testing of the instructional model by its Compositions（N=5）

Table 10. Mean and ICC for Expert Validation Results of the Instructional Model Components

Item	Mean	Interpretation	ICC	Level
Principles (1-6)	4.24	High	0.82	Good reliability
Learning Steps (1-5)	4.24	High	0.82	Good reliability
Objectives (1-5)	4.6	Highest	0.8	Good reliability
Instructor's Role (1-5)	4.32	High	0.78	Good reliability
Learner's Role (1-5)	4.32	High	0.8	Good reliability
Media & Resources (1-5)	4.32	High	0.78	Good reliability
Assessment (1-9)	4.67	Highest	0.82	Good reliability

The table presents the expert evaluation results for each component of the instructional model. The ratings were provided by five field experts using a five-point Likert scale, assessing seven core components of the model: teaching principles, learning steps, learning objectives, instructor roles, learner roles, media and resources and assessment. The intra-class correlation coefficient (ICC) was calculated for each component to examine the consistency and reliability of the expert ratings.

The results show that the average scores for all components were between 4.0 and 5.0, which reflects a high level of appropriateness. The ICC values were between 0.78 and 0.82 and meet the good reliability standards suggested by Koo and Li (2016). This indicates strong agreement among the experts in every area. Overall, the findings suggest that the instructional model has a solid structure, is based on sound scientific principles, and is practical and suitable for use.

The researchers evaluated the quality of the instructional model based on several components, including teaching principles, learning steps, teaching objectives, teacher roles, student roles, media and resources, and assessment. Five experts assessed the accuracy and suitability of the model. The average score for every component was above 4.00, which falls within the high or highest level, showing that the experts strongly approved of the model's overall design. The ICC results also showed good reliability. The values were 0.82 for teaching principles, 0.82 for learning steps, 0.80 for teaching objectives, 0.78 for teacher roles, 0.80 for student roles, and 0.78 for media and resources. Based on commonly accepted standards, ICC values between 0.75 and 0.90 indicate good reliability. This means that the experts' judgments were highly consistent across all areas. Overall, the teaching model demonstrates a sound structure, scientifically supported content, and strong practicality and reliability.

4.7 Development and Validation of the Lesson Plan

In this study, six lesson plans were developed for the BIM (Revit) course following the aforementioned steps. The six course plans were reviewed by five experts using a five-point Likert scale, covering (1) instructional objectives, (2) teaching strategies and learning activities, (3) class structure and pacing, (4) integration of resources and technology, and (5) assessment and feedback design. These data measured the extent to which each lesson met standards, supported inquiry-based learning, managed class flow, utilized technology, and provided actionable feedback, providing a clear map of strengths and gaps for targeted course improvement. The evaluation results can be summarized as presented in Table 11.

Table 11. Expert Validation Results of the Course Plan

Item	Mean	Interpretation	ICC	Level
Lesson plan 1	4.24	High	0.82	Good reliability
Lesson plan2	4.36	High	0.86	Good reliability
Lesson plan3	4.64	Highest	0.86	Good reliability
Lesson plan4	4.44	High	0.87	Good reliability
Lesson plan5	4.24	High	0.82	Good reliability
Lesson plan6	4.30	High	0.76	Good reliability

Based on the expert evaluation, the results show that all lesson plans received high ratings, with mean scores between 4.24 and 4.64. The reliability was also strong, with ICC values ranging from 0.76 to 0.87. These findings indicate that the lessons is rational, feasible, and educationally robust. The overall course design was viewed as high quality and consistent. The expert review further confirmed that the instructional model is well founded and practical, supporting the stability of its content in professional assessment.

After the lessons were validated by experts, a pilot study was carried out to examine the practicality of the instructional model. The purpose was to identify possible challenges and refine the teaching activities and tools. The results of the pilot study are presented in Table 12.

Table 12. Pilot Study Observations, Student Feedback, and Revisions

Lessons	Student Performance Data	Student Feedback	Modification & Improvement
Lesson 1	24% (11 students) could independently complete family modeling; 64% (29 students) required partial guidance; 12% (5 students) encountered difficulties in software operation	Some students reported unfamiliarity with the software interface and too many technical terms	Add software operation demonstration videos; provide a BIM terminology glossary
Lesson 2	30% (14 students) could independently complete modeling; 58% (26 students) completed with lower efficiency; 12% (5 students) failed to complete the task	Students reported that the drawing output steps were unclear	Provide a drawing output flowchart; conduct step-by-step practice
Lesson 3	38% (17 students) mastered parametric methods; 47% (21 students) completed partial parameter settings; 15% (7 students) made errors	Students felt the logic of parameter functions was complicated	Add parameter function case studies; provide simplified exercises
Lesson 4	45% (20 students) completed complex components such as stairs/roofs; 42% (19 students) completed partially; 13% (6 students) failed to complete	Students felt the task time was insufficient	Adjust task difficulty; add supplementary after-class exercises
Lesson 5	58% (26 students) completed the small villa project; 33% (15 students) completed partially; 9% (4 students) failed to integrate	Some students reported unbalanced group collaboration	Provide clear division-of-work templates; strengthen training on collaboration tools
Lesson 6	67% (30 students) completed the full project and presentation; 29% (13 students) completed partially; 4% (2 students) were underprepared	Students felt the presentation time was too short	Extend presentation session time; provide a presentation template

Over the six-week pilot study, students showed steady improvement in their performance. The proportion of incomplete tasks dropped from 12 percent in Lesson 1 to only 4 percent in Lesson 6. This pattern suggests that the instructional model helped strengthen their BIM modeling skills. In the next stage, the model will be refined based on the pilot findings and then implemented with a larger group of students to more fully assess its effectiveness.

5. Discussion

This study developed and validated an instructional model for BIM modeling tailored to architectural engineering students by integrating the theoretical foundations of systematic instructional design (Gagné, 2005) and social constructivist learning theory (Vygotsky, 1978). The model rigorously adheres to the systematic framework of "principles–objectives–process–roles–assessment" (Morrison et al., 2013), emphasizing knowledge acquisition through pre-class self-directed learning (Brame, 2013) and promoting knowledge internalization and competency development via in-class collaborative tasks. This approach embodies the core principle that "learning occurs through social interaction" (Siriwattana & Sanrattana, 2023). Compared with traditional teacher-centered instruction, this framework embeds learners' agency within authentic engineering contexts, enabling simultaneous construction and application of knowledge, which aligns closely with the interdisciplinary coordination and parametric design demands inherent in BIM practice. The two-phase mixed-methods research not only empirically confirmed students' strong preference for structured pre-class materials, authentic tasks, and clear evaluation criteria (mean ≥ 4.20), but also reflected the model's successful implementation of student-centered and socially enriched learning processes. High expert ratings for all components (mean between 4.0–5.0) along with good reliability (ICC 0.78–0.82) demonstrate the model's theoretical soundness, structural consistency, and practical feasibility.

The model validation phase involved rigorous evaluation by five field experts using a five-point Likert scale. All six core components of the model were rated between 4.24 and 4.64, indicating a "high" to "highest" level of approval. The Intraclass Correlation Coefficient (ICC) ranged from 0.76 to 0.87, demonstrating good inter-rater reliability and structural consistency (Koo & Li, 2016). Notably, the "learning steps" and "assessment methods" components achieved an ICC of 0.82, reflecting strong logical sequencing and evaluative rigor. This indicates that the model possesses high reproducibility and cross-team transferability in instructional process design and assessment, maintaining consistent implementation quality and measurement fidelity across different teaching teams. Furthermore, the six lesson plans developed based on the model also received high expert ratings (mean ≥ 4.24), confirming the model's practicality and transferability across instructional settings.

A pilot study involving 45 students provided further evidence of the model's effectiveness. Students exhibited positive learning attitudes and active engagement, particularly during collaborative tasks and formative feedback sessions. During group modeling and conflict-resolution tasks, students not only significantly improved their proficiency with software such as Revit, but also developed core professional soft skills in communication, task division, and decision-making, which are highly aligned with the competency requirements of BIM-related roles. Recurring issues identified during implementation led to refinements in resource organization, activity scheduling, and tool integration, thereby enhancing the model's stability and adaptability. The finding explicitly confirms that the design elements driving the measurable improvements in engineering education are rooted in the shift toward interactive engagement, problem-based work, and real-time support. The findings align strongly with prior research demonstrating the effectiveness of the Flipped Classroom (FC) in engineering education. FC significantly improves student achievement, supporting the positive learning outcomes observed (Bishop & Verleger, 2013; Lo & Hew, 2019; Zhao, Lee, Runshe, & Krousgrill, 2021). In addition, collaborative learning (CL) is highly relevant to the engineering profession, and studies have shown it is an indispensable method for preparing students for the workplace. Collaborative environments strengthen learners' commitment through shared goals and accountability (Dass et al., 2021) and it promote deep learning and higher cognitive engagement (Mercier et al., 2023).

6. Conclusion

In conclusion, the proposed instructional model effectively addresses the growing demand for practical skills and collaborative competencies in modern engineering education. By combining flipped classroom and collaborative learning strategies, it offers a scientifically grounded, practical, and scalable framework for enhancing BIM modeling instruction. The framework ensures depth and personalization of knowledge input before class, while fostering socialization and transfer of knowledge through collaboration during class, thus forming a "learn–apply–reflect" cycle that strengthens both technical ability and engineering thinking alongside team coordination literacy —

providing a transferable and actionable pathway for similar engineering skill courses. Future research is recommended to implement the model across diverse institutional contexts and to examine its long-term impact and cross-cultural applicability.

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