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Research Paper

Applying TPACK and the Flipped Classroom to the Design and Use of a 3D Specimen Library for the Magnetic Field Chapter in Grade 12 Physics

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ABSTRACT

Magnetic-field topics in Grade 12 Physics require students to reason about objects and relations that are partly invisible: field lines, vector direction, the region of an approximately uniform field, and the relative positions of devices in experiments on magnetic force. In many school settings, however, real apparatus is limited in number or difficult for every student to observe at the same time. This study therefore developed a 3D specimen library for the Magnetic Field chapter and proposed a way to use it through the Technological Pedagogical Content Knowledge (TPACK) framework and a flipped classroom sequence. The research followed a design-and-development approach. The work combined a review of relevant studies, a needs survey with physics education students, curriculum and equipment analysis, 3D modeling in SketchUp, and the construction of lesson and evaluation tools. Of 157 invited students, 145 valid responses were analyzed descriptively. Respondents valued the teaching support offered by 3D specimens (M = 4.00, SD = 0.92) and their role in stimulating student interest and exploration (M = 3.85, SD = 0.99), but their actual experience was modest: 52.41% had never heard of a 3D library for this chapter and 40.69% had only heard of one without using it. The main barriers were the absence of suitable ready-made 3D resources (54.5%) and limited technical skills (49.0%). Five specimens were produced: a straight magnet with magnetic field lines, a U-shaped magnet, an ammeter, a power supply, and a magnetic-force measuring apparatus. A flipped process for Lesson 14, Magnetic Field, and a TPACK-SAMR evaluation rubric were also designed. The study contributes a feasible model for organizing 3D learning resources in physics teaching; classroom-scale validation of learning outcomes remains a necessary next step.

Keywords: TPACK; flipped classroom; 3D specimen library; magnetic field; Grade 12 Physics; digital learning resources

INTRODUCTION

Digital transformation in school education has changed the way teachers prepare learning materials, but the change is most meaningful when technology helps students see, manipulate, and discuss ideas that are otherwise hard to grasp. Physics is a clear example. In the Magnetic Field chapter of Grade 12 Physics, students do not encounter magnetic fields as visible objects. They infer them from effects on magnets or currents and from representations such as magnetic spectra, field lines, and vector rules. The lesson therefore depends heavily on visualization, guided observation, and well-sequenced classroom discussion.

The practical situation in many classrooms does not always support those requirements. Sets of magnets, coils, ammeters, power supplies, and magnetic-force apparatus may be insufficient, worn out, or too small for a large class to observe together [1]. With only textbook drawings or two-dimensional slides, students can memorize field-line patterns while still misunderstanding the three-dimensional distribution of a field or the role of each device in an experiment [2]. Earlier work on 3D virtual laboratories, 3D modeling, digital books with 3D animations, and virtual reality in physics has shown that interactive spatial representations can support conceptual understanding, motivation, and problem solving [3], [4], [5], [6].

In Vietnam, the 2018 General Education Physics Curriculum gives considerable weight to inquiry, experiment, visual means, and the development of student competencies [7]. The Grade 12 textbook and the official minimum-equipment list also confirm that the Magnetic Field chapter is closely linked with experimental devices and visual representations [8], [9]. A gap nevertheless remains between curriculum expectations and the resources that teachers or prospective teachers can conveniently use. A 3D library designed specifically for the Magnetic Field chapter could make common apparatus easier to observe, revisit, and connect with learning tasks.

The present study was built around three questions. First, how ready are prospective physics teachers to use 3D learning materials, and what support do they need? Second, which representative 3D specimens can be designed for the Magnetic Field chapter, and what teaching role should each one serve? Third, how can the TPACK framework and the flipped classroom model guide the use and evaluation of such a library?

LITERATURE REVIEW

3D digital specimens and 3D specimen libraries

A 3D model represents an object in a virtual three-dimensional space through geometric elements such as points, edges, surfaces, and polygonal meshe [10], [11]. When a real or instructional object is digitized so that its visible structure can be stored, shared, and inspected, it functions as a 3D digital specimen. Photogrammetry and similar digitization procedures have made this type of specimen increasingly practical, especially where direct access to the original object is limited [12]. Large repositories such as Morpho Source and PaleoView3D show how 3D specimen data can be archived with metadata and reused for research or learning without requiring physical handling of the object [13], [14].

In this study, a 3D specimen is understood as an interactive digital learning object that reproduces the shape and instructional features of a physics device or phenomenon. A 3D specimen library is not merely a folder of files; it is a structured collection in which models are named, described, organized by content, and made accessible to teachers and students. For teaching purposes, useful interaction includes rotating the object, zooming in on details, changing viewpoints, comparing components, and connecting observations with a learning task.

TPACK and SAMR in technology-supported physics teaching

The TPACK framework extends Shulman's idea of pedagogical content knowledge by describing effective technology integration as the intersection of content knowledge, pedagogical knowledge, and technological knowledge [15]. For the topic of magnetic fields, content knowledge concerns concepts such as field lines, magnetic-force direction, and experimental apparatus; pedagogical knowledge concerns how students are guided from observation to explanation; and technological knowledge concerns how 3D models are accessed and manipulated. TPACK is useful because it asks teachers not simply whether a tool is modern, but whether it serves a clearly identified learning difficulty [16], [17], [18].

SAMR, consisting of Substitution, Augmentation, Modification, and Redefinition, provides a second lens for judging the depth of technology use [19], [20], [21]. In a low-level use, a 3D magnet may simply replace a picture in the textbook. At a richer level, students can rotate the model, inspect field-line density, annotate screenshots, compare their explanations, and produce evidence of reasoning that would be difficult to obtain from a flat drawing. In this study, TPACK was used as the main design logic, while SAMR helped to reflect on the expected degree of instructional change.

Flipped classroom and the use of 3D materials

A flipped classroom moves the initial encounter with content outside class and reserves classroom time for feedback, collaboration, problem solving, and teacher support [22]. This arrangement is suitable for physics because some preparatory activities - watching a short explanation, observing a model, noting an unclear point - can be completed individually before the lesson, while classroom time can be used for checking misconceptions and applying ideas to experimental situations. Studies on flipped learning, blended learning, and immersive visualization have reported benefits for active participation and self-study when the process is carefully organized [23], [24], [25], [26], [27].

For a 3D specimen library, the flipped model gives the resource a clear pedagogical position. Before class, a model can support first observation and question generation. During class, the same model becomes a shared object for discussion, correction, and explanation. After class, students can return to it to revise their work. Thus, the library is treated as part of a learning sequence rather than as a decorative digital supplement.

MATERIALS & METHODS

Research design

The study used a research-and-development orientation. The process included reviewing theoretical and empirical studies; surveying prospective physics teachers; analyzing the Grade 12 Magnetic Field chapter; selecting representative devices; modeling, editing, and optimizing 3D specimens; arranging the specimens into a library; and developing a flipped lesson process together with evaluation tools. The design decisions were checked against TPACK so that each specimen had a defined content role, a pedagogical use, and a technological function.

This paper reports the design stage and a preliminary needs-based feasibility analysis. It does not claim experimental evidence of learning gains in Grade 12 classrooms. Such evidence requires a later classroom trial with pre-tests, post-tests, observations, and delayed measures.

Participants and survey instrument

The needs survey was administered to physics education students at Thai Nguyen University of Education, Thai Nguyen University. They were selected because they represent the next generation of physics teachers and will soon be expected to use digital resources in school practice. The survey invitation reached 157 students from different cohorts; after screening for completeness, 145 responses were retained for analysis.

The questionnaire asked about background information, familiarity with information technology, experience with 3D learning materials, perceived teaching value, perceived benefits for students, self-assessed capacity to design and implement lessons with 3D specimens, barriers to use, and support needs. Most attitudinal and capacity items used a five-point Likert scale. Grouped constructs were checked using Cronbach's alpha.

3D modeling procedure

Five devices were selected from the curriculum, textbook, and minimum-equipment requirements: a straight magnet with magnetic field lines, a U-shaped magnet, an ammeter, a power supply, and a magnetic-force measuring apparatus [7], [8], [9]. These specimens were chosen because they support key concepts in the chapter and because their shape or arrangement benefits from observation from more than one viewpoint.

The models were constructed in SketchUp, a commonly used 3D modeling environment for visual design and spatial representation [28], [29], [30]. The workflow followed five steps: selecting the device, collecting information or direct measurements, building the model, correcting and simplifying details, and exporting the model for online viewing. Details that were meaningful for teaching, such as terminals, scales, poles, field-line direction, or relative positions of components, were retained. Very small or non-instructional details were simplified to keep the models light enough for classroom use.

Statistical Analysis

Survey data were summarized using frequencies, percentages, means (M), standard deviations (SD), and Cronbach's alpha. Because the purpose of this phase was to identify needs and inform product design, the analysis was descriptive rather than inferential.

RESULT

Survey characteristics and initial experience

The final sample included 145 valid responses. Table 1 presents the main background characteristics and the respondents' initial contact with 3D learning materials for the Magnetic Field chapter.

Table 1. Background characteristics and initial experience (N = 145)

Indicator	Result
Gender	Male: 53 (36.55%); Female: 88 (60.69%); Other/not reported: 4 (2.76%)
Year of study	Year 1: 77 (53.10%); Year 2: 21 (14.48%); Year 3: 27 (18.62%); Year 4: 20 (13.79%)
Familiarity with information technology	M = 3.06, SD = 0.74
Experience with a 3D library for the Magnetic Field chapter	Never heard of it: 76 (52.41%); heard of it but never used: 59 (40.69%); observed a teacher using it: 6 (4.14%); self-operated: 2 (1.38%); used to design a lesson: 2 (1.38%)

The data indicate a clear access gap. Although students rated their familiarity with information technology at a moderate level (M = 3.06, SD = 0.74), 52.41% had never heard of a 3D library for the chapter and 40.69% had only heard of it without use. Only a few had watched a teacher operate such a resource or had used one themselves. In other words, the difficulty is not simply a lack of interest; it is also a lack of available resources and guided practice.

Perceptions, capacities, barriers, and needs

Table 2 summarizes the principal perception and capacity constructs. The reliability coefficients were acceptable for exploratory educational research. Respondents showed a positive view of the teaching value of 3D specimens and their potential role in supporting student interest and exploration. Self-assessed capacities were lower, particularly for the practical implementation and evaluation of lessons using 3D resources.

Table 2. Summary of perception and capacity constructs

Construct	Cronbach's alpha	Mean +/- SD	Interpretation
Perceived teaching-support value of 3D specimens	0.82	4.00 +/- 0.92	Positive

Perceived role for students	0.78	3.85 +/- 0.99	Positive
Capacity to design learning activities with 3D specimens	0.81	3.58 +/- 0.80	Moderate to good
Capacity to implement and evaluate learning with 3D specimens	0.87	3.54 +/- 0.81	Moderate to good

The barrier pattern, shown in Table 3, explains why positive perception has not yet become regular practice. More than half of the respondents identified the absence of an available, suitable 3D resource library as a difficulty, and nearly half pointed to limited technical skills. Infrastructure and pedagogical-design skills were also notable concerns. By contrast, only 8.3% considered 3D unnecessary, suggesting that resistance to the idea itself is not the dominant problem.

Table 3. Main barriers to using 3D learning materials

Barrier	**n**	**%**
Lack of an available and suitable 3D resource library	79	54.5
Lack of technical skills for operation and integration	71	49.0
Lack of devices or infrastructure	59	40.7
Lack of pedagogical design skills	48	33.1
Lack of preparation time	28	19.3
Do not see 3D as necessary	12	8.3

Support needs were consistent with this interpretation. Respondents expressed strong agreement with developing a specialized 3D specimen library (M = 4.05, SD = 0.84). They also wanted sample lesson plans and activity scripts (M = 3.92, SD = 0.86), concrete guidance on using the library (M = 3.88, SD = 0.84), and a web- or LMS-based repository that could be reached easily (M = 3.86, SD = 0.86). The product therefore needed to be designed as a teaching ecosystem rather than a set of isolated models.

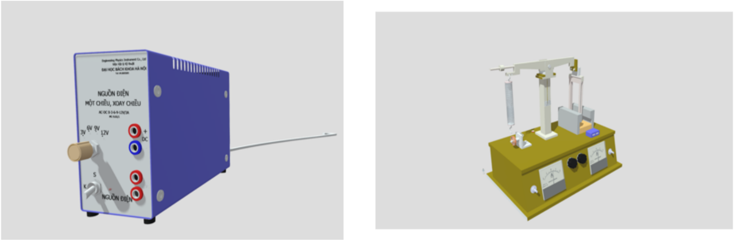
Designed 3D specimen library

The design phase produced five representative specimens. Each specimen was associated with a particular content area and a specific teaching function, as summarized in Table 4.

Table 4. 3D specimens and their pedagogical functions

3D specimen	**Physics content supported**	**Main pedagogical function**
Straight magnet with magnetic field lines	Magnetic field, magnetic spectrum, magnetic field lines	Supports observation of the spatial form, direction, and density of field-line representations around a bar magnet.
U-shaped magnet	Nearly uniform magnetic field	Helps students locate the region between two poles where the field is commonly represented as almost uniform.
Ammeter	Current measurement in experimental circuits	Guides observation of the scale, pointer, terminals, and role of current measurement.
Power supply	Current generation and circuit arrangement	Helps students recognize terminals, voltage adjustment, and connection positions before using real apparatus.
Magnetic-force measuring apparatus	Magnetic force on a current-carrying conductor	Clarifies the relative positions of magnet, conductor, ammeter, force meter, and supporting frame.

(a) Straight magnet and field lines (b) U-shaped magnet (c) Ammeter



(d) Power supply (e) Magnetic-force apparatus

Figure 1. Selected 3D specimens designed for the Magnetic Field chapter.

The specimens are intended for rotation, zooming, and observation from several viewpoints. They do not replace real experiments. Their main value is preparatory and explanatory: students can inspect apparatus before handling it, observe details that may be hidden or too small in a classroom demonstration, and form an initial spatial representation before working with physical devices.

Flipped classroom process for Lesson 14: Magnetic Field

The 3D library was integrated into a three-phase flipped classroom design for Lesson 14, Magnetic Field. The focus was the continuity between independent preparation, classroom clarification, and post-class correction.

Table 5. Flipped-classroom use of the 3D library

Phase	Teacher and student activities	Expected evidence
Before class	Teacher sends the video lesson, library link/QR code, and Padlet task. Students watch, observe the straight magnet model, answer guiding questions, and submit notes or questions.	Self-study notes; submitted answers; questions and misconceptions collected before class.
During class	Teacher reviews self-study results, clarifies misconceptions, uses 3D models to discuss field-line direction and density, and organizes pair/group tasks related to field-line direction and right-hand rules.	Corrected notes; group solutions; oral explanations; evidence of interaction with the model.
After class	Students revise their products, identify what they understood or misunderstood, and resubmit corrected work. Teacher evaluates process and product evidence.	Completed learning product; self-correction notes; teacher assessment.

Evaluation tools based on TPACK and SAMR

A TPACK-based rubric was prepared to evaluate the quality of technology integration. The rubric considers whether the physics content warrants 3D support, whether the model represents the target concept accurately, whether learners actually use the available technological affordances, and whether the observation tasks are connected with assessment. SAMR was used as a supplementary reflection tool to distinguish simple display from transformed learning activity.

Table 6. Condensed TPACK-SAMR evaluation framework

Dimension	**Key evaluation question**	**SAMR orientation**
CK/PCK	Is the selected content difficult enough to justify 3D support, and is the learner difficulty clearly identified?	Substitution to modification
TCK	Does the selected 3D model represent the target physics concept or apparatus accurately and clearly?	Augmentation
TK	Are rotation, zooming, and viewpoint changes used deliberately rather than passively?	Augmentation
TPK	Do learners have explicit observation, description, analysis, and discussion tasks linked to the model?	Modification
TPACK	Is the 3D model connected with before-class, in-class, and after-class learning, as well as assessment?	Modification to redefinition

DISCUSSION

The results point to a practical and familiar tension in technology-supported teaching. Prospective physics teachers recognize that 3D materials can help students approach magnetic-field concepts, yet they have limited experience with a specialized library and little opportunity to practice using it in a lesson. This finding is consistent with the basic premise of TPACK: technology integration is not achieved by adding a tool to an existing lesson; it requires a match between the content problem, the learning task, and the affordances of the tool [15], [16], [17], [18].

The five specimens developed in this study respond to different instructional needs. The straight magnet with field lines supports discussion of the spatial distribution and direction of magnetic field lines. The U-shaped magnet helps students locate the region usually represented as an approximately uniform magnetic field. The ammeter and power supply prepare students to recognize terminals, scale markings, and connection positions. The magnetic-force apparatus helps them see the relative positions of the magnet, conductor, ammeter, force meter, and supports before encountering the real equipment.

A useful caution is needed here. A 3D field-line model does not make the magnetic field literally visible. It is a representation, and students still need guidance to understand that field lines are a scientific convention. Precisely for that reason, the model should be accompanied by questions such as where the lines are denser, why arrows are shown, which regions are stronger or weaker, and how the representation relates to an observed magnetic spectrum. The pedagogical work around the model matters as much as the model itself.

SAMR helps clarify the same point. If a teacher uses a specimen only as an attractive replacement for a textbook image, the activity remains at substitution. When students rotate and zoom to identify poles, terminals, scales, or hidden structural relations, the activity moves toward augmentation. When the lesson is redesigned so that students observe before class, submit questions, compare views during group work, and revise explanations afterwards, the task reaches modification. Redefinition may be approached when students create annotated evidence, inquiry records, or explanatory products that would be difficult to produce without the interactive library [19], [20], [21].

The flipped classroom is especially suitable for this kind of resource. Before class, students can observe a model at their own pace and record uncertainties. During class, the teacher can use those questions to diagnose misconceptions and connect digital observation with real apparatus. After class, students can revisit the model, correct their answers, and consolidate the relationship between representation and physical device. This sequence agrees with flipped-learning studies that emphasize preparation, active classroom engagement, and feedback [22], [23], [24], [25], [26], [27].

The study also has limitations. The survey was conducted at one university and involved prospective teachers, not Grade 12 students. The product was evaluated through need, design logic, and preliminary feasibility rather than through a controlled classroom experiment. Future research should test the library in real Grade 12 classes, combine achievement tests with observation and interview data, and examine not only immediate understanding but also spatial reasoning, motivation, and retention over time.

CONCLUSION

This study designed a 3D specimen library for the Grade 12 Magnetic Field chapter and proposed a way to use it through TPACK and the flipped classroom model. The needs survey showed that prospective physics teachers value 3D learning materials, but their use is constrained by lack of resources, technical confidence, infrastructure, and pedagogical guidance. Based on curriculum and equipment analysis, five specimens were produced: a straight magnet with magnetic field lines, a U-shaped magnet, an ammeter, a power supply, and a magnetic-force measuring apparatus.

The proposed flipped sequence organizes the library into before-class observation, in-class clarification and application, and after-class correction. The TPACK-based rubric, supported by SAMR reflection, offers a practical way to evaluate whether the technology is connected with physics content, learning activity, and assessment. Within the limits of a design-stage study, the 3D specimen library appears feasible and pedagogically meaningful for visualizing magnetic-field concepts and preparing students to work with real experimental equipment. Empirical classroom validation is the next task.

Declaration by Authors

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