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Work in Progress: LecXbit – From Chalkboard to Classroom Demonstrations – The Role of Physical Models in Bridging Abstract Concepts and Student Learning

Dr. Hamid S Timorabadi P.Eng., University of Toronto

Hamid Timorabadi received his B.Sc, M.A.Sc, and Ph.D. degrees in Electrical Engineering from the University of Toronto. He has worked as a project, design, and test engineer as well as a consultant to industry. His research interests include the application of digital signal processing in power systems and engineering education.

Jenny Chung, University of Toronto
Linh Khanh Dinh

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Abstract

Many foundational engineering concepts—such as electromagnetic fields, rotating machines, and Faraday's and Lenz's laws—are mathematically rigorous yet difficult for students to visualize. Traditional lectures often rely on static representations, requiring students to imagine dynamic and invisible processes, which can lead to weak conceptual understanding. Lecture-embedded physical demonstrations offer a way to make these abstractions tangible and directly observable.

This paper introduces LecXbit (Lecture eXhibition), a platform of low-cost, portable physical demonstration kits designed for use during lectures. LecXbit is based on the idea that abstract concepts are better understood when reinforced through immediate physical manifestation. As a work-in-progress, the paper describes two classroom implementations that illustrate the platform's design and early use.

The first implementation, in a third-year energy systems course, used transparent and modular components to help students visualize magnetic flux and machine structure. The second, in a second-year electromagnetics course, enabled hands-on interaction with coils and magnets to demonstrate Faraday's and Lenz's laws. Preliminary classroom observations and student feedback suggest improved conceptual clarity, engagement, and intuition compared to traditional lecture approaches.

These early observations indicate that physical demonstrations can be particularly effective when used to complement analytical instruction. By linking abstraction with immediate physical experience, LecXbit offers a practical and scalable approach to supporting conceptual understanding in electromagnetics-related courses.

1. Introduction and Motivation

Many foundational topics in electrical and computer engineering—such as electromagnetic fields, rotating magnetic fields, and the operating principles of electric machines—are mathematically rigorous yet conceptually challenging for students [1], [2]. While the underlying laws are compactly expressed through equations, the associated physical phenomena are dynamic, spatial, and often invisible. As a result, students are frequently asked to reason about time-varying fields, induced currents, and electromechanical interactions based primarily on static diagrams or symbolic representations [3].

Traditional lecture-based instruction typically relies on chalkboard derivations, textbook figures, and slide presentations. Although these approaches are effective for the formal development of theory, they can leave students with limited intuition and difficulty linking equations to physical behavior, particularly in electromagnetics-related courses [4], [5]. This gap is especially pronounced in electric machines education, where students often struggle to visualize magnetic flux, phase relationships, and cause-and-effect mechanisms [6].

To address this challenge, this paper introduces LecXbit (Lecture eXhibition), a platform of low-cost, portable physical demonstration kits designed to be embedded directly into lectures. LecXbit is not intended to replace mathematical exposition or simulations—which have proven instructional value [7]—but to complement them by allowing students to directly observe the physical manifestation of abstract concepts introduced moments earlier. This approach aligns with prior work showing that conceptual understanding improves when abstract reasoning is closely coupled with concrete experience [8].

This paper is presented as a Work-in-Progress (WIP) and focuses on the design philosophy of LecXbit and its initial classroom deployment in two courses: (1) a third-year energy systems course emphasizing AC machines, and (2) a second-year introductory electromagnetics course covering Faraday's and Lenz's laws. Preliminary observations from student feedback and classroom engagement suggest that lecture-embedded physical demonstrations can support conceptual understanding and confidence. Larger-scale validation and longitudinal studies are planned as future work.

2. Related Work and Pedagogical Context

The use of physical models to support learning is well established across STEM disciplines. In chemistry and molecular biology, ball-and-stick models are routinely used to help students reason about molecular geometry and bonding—phenomena that cannot be directly observed [9]. An example is shown in Figure 1, where a physical model provides a tangible representation that supports spatial reasoning and conceptual understanding.

In engineering education, particularly in electromagnetics and electric machines, a wide range of visualization strategies has been explored. Computer simulations and animations are commonly used to illustrate electric and magnetic field distributions, rotating magnetic fields, and machine operation [7], [10]. Prior studies have shown that simulations can enhance conceptual understanding by making invisible quantities visible and enabling parametric exploration [11]. However, simulations remain mediated representations: students observe results on a screen rather than interacting with physical systems, and the connection between mathematical abstraction and real-world behavior may remain indirect [12].

Commercial instructional kits and laboratory demonstrators provide physical interaction but are often designed for laboratory environments rather than lectures. These systems can be expensive, bulky, require specialized infrastructure, or involve safety constraints that limit their practicality in large classroom settings [13]. As a result, many instructors rely on instructor-only demonstrations or static hardware displays that lack real-time interactivity.

Recent work in engineering education has emphasized the value of in-lecture demonstrations that are tightly integrated with conceptual instruction. When demonstrations are brief, safe, and visually clear, they can serve as cognitive anchors that reinforce abstract reasoning rather than distract from it [14], [15]. Despite this, the design space for lecture-ready physical demonstration tools—portable, low-cost, robust, and pedagogically aligned—remains underexplored, particularly in electromagnetics and electric machines education.

LecXbit is positioned within this gap. Unlike purely virtual tools, it enables direct physical interaction and real-time cause-and-effect observation. Unlike traditional laboratory equipment, it is designed for lecture deployment, rapid setup, and repeated use across sections. The platform builds on prior insights from physical modeling and simulation-assisted teaching while emphasizing immediacy, portability, and conceptual clarity.

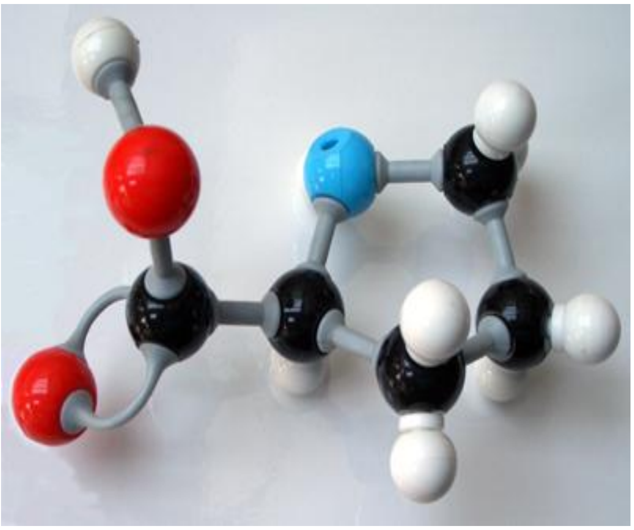

Figure 1. Ball-and-stick molecular model of proline, illustrating bond geometry and molecular structure. Image adapted from Wikimedia Commons [16].

3. Problem Statement

Electromagnetic field theory and electric machine fundamentals are widely regarded as among the most challenging topics in electrical and computer engineering curricula. Developing intuition in these subjects requires students to reason about invisible, time-varying phenomena and to connect mathematical expressions to physical cause-and-effect relationships. Core laws such as Faraday’s Law and Lenz’s Law are central to this understanding, yet students often struggle to visualize how changes in magnetic fields lead to induced voltages, currents, and mechanical effects.

Traditional instructional approaches based on chalkboard derivations, static diagrams, or slide-based presentations are effective for conveying formal theory, but they can leave students with limited physical intuition. In particular, students frequently report difficulty translating equations into mental models that explain observed system behavior. This gap can hinder deeper understanding and confidence, especially when students encounter more complex systems such as rotating machines.

The problem addressed in this work is how to reduce the conceptual barrier associated with electromagnetic phenomena during lectures without sacrificing rigor or instructional efficiency. We hypothesize that lecture-embedded physical models, when used to complement analytical instruction, can help students directly observe the effects and implications of fundamental laws. By making abstract concepts physically tangible, such models have the potential to improve engagement, intuition, and conceptual understanding. LecXbit was developed to explore this approach within standard classroom constraints.

4. Technical Design and Design Requirements

The LecXbit models were designed to support in-lecture demonstrations of electromagnetic principles while satisfying practical constraints associated with classroom deployment. Although each model targets a specific concept, a common set of design requirements guided their development. These requirements emphasize portability, safety, and cost, ensuring that the models can be repeatedly used in standard lecture environments. The shared design requirements are summarized in Table 1.

Table 1. Design Requirements for LecXbit Models

Requirement	Justification	Metric
Portability	Models must be easily transported and deployed by a single instructor during lectures.	All components fit within a standard ~30 L backpack (approx. 19.0 in × 11.25 in × 7.0 in).
Safety	Demonstrations must operate safely in close proximity to students while clearly illustrating electromagnetic effects.	Low-voltage, low-current operation measurable with standard laboratory multimeters.
Cost	Models should be affordable and reproducible compared to commercial instructional kits.	Material cost substantially lower than commercially available demonstration systems.

While these shared requirements ensure consistency across the LecXbit platform, each model also incorporates additional concept-specific considerations based on the physical phenomenon being demonstrated and the associated learning objectives.

As an illustrative example, one LecXbit model targets Faraday's Law of electromagnetic induction, which states that a time-varying magnetic flux through a conducting loop induces an electromotive force (EMF) proportional to the rate of change of flux. From an instructional perspective, two observable effects are of primary interest:

1. The appearance of an induced current when the conducting loop is closed.
2. The presence of a measurable induced voltage (EMF) across the loop terminals.

The corresponding LecXbit implementation was designed to make both effects directly observable during lecture, allowing students to relate magnetic field variation to induced electrical response.

4.1 Model A: Induced Current and EMF (Faraday's Law)

Model A was developed to demonstrate electromagnetic induction by exposing a conducting coil to a time-varying magnetic flux generated by a moving permanent magnet. The design emphasizes visual clarity, direct measurement, and clear cause-and-effect observation, which are important for reinforcing Faraday's Law during lectures.

The model consists of a stationary coil with accessible terminals, positioned such that changes in magnetic flux can be introduced through controlled motion of a magnet. The coil inductance and geometry were selected to ensure that induced voltages and currents remain within safe operating limits while still being easily measurable using standard laboratory multimeters, in accordance with the safety requirement in Table 1.

The physical form factor of the model was inspired by Helmholtz-style coil arrangements commonly used in instructional demonstrations (Figure 2), providing a familiar reference point for students while maintaining a compact and lecture-friendly footprint. To enhance conceptual transparency, one side of the enclosure was fabricated using a transparent material, allowing students to clearly see the coil windings and terminal connections during operation.

Figure 2. Helmholtz-style coil arrangement commonly used in instructional demonstrations (commercial examples include PASCO SE-9626 [17]).

A custom enclosure was designed using 3D modeling tools to support the coil and measurement terminals (Figure 3). The final assembly was fabricated using a combination of 3D-printed structural components, laser-cut transparent acrylic, and nylon-coated copper wire for the coil winding. This construction approach balances robustness, visibility, and low production cost, while enabling rapid setup and teardown during lectures.

Through this design, students can directly observe how changes in magnetic flux produce measurable electrical effects, reinforcing the connection between the mathematical formulation of Faraday's Law and its physical manifestation.

(a) (b)

Figure 3. Faraday's Law demonstration module showing two sides of the physical model: (a) front side displaying the governing equation and electrical terminals, and (b) back side with explanatory content on Faraday's and Lenz's laws, including historical context.

4.2 Model B: Electromechanical Energy Conversion and Lenz's Law

Model B was developed to illustrate the role of electromagnetic induction and Lenz's Law in rotating electrical machines. Lenz's Law states that the induced current in a conductor produces a magnetic field that opposes the change in magnetic flux that caused it. While this principle is fundamental to the operation of AC and DC machines, students often find it difficult to visualize using static diagrams alone.

The LecXbit generator model exposes key internal elements such as coils, magnetic fields, and mechanical motion. This allows students to observe how induced currents generate opposing magnetic effects. By manipulating the system and observing changes in electrical response, students can relate magnetic flux variation to induced current direction and the resulting electromagnetic behavior.

This model was designed to emphasize cause-and-effect relationships between magnetic flux changes, induced currents, and electrical response, rather than to replicate the full complexity of industrial machines. As with Model A, low-voltage operation and modular construction support safe classroom use and rapid deployment.

Figure 4 illustrates the internal rotor–stator structure of the LecXbit generator with dual-output (AC and DC) connections, while Figure 5 shows a separate assembled three-phase AC system used to generate three-phase voltages and demonstrate three-phase machine operation. Together, these systems allow students to engage with the physical mechanisms underlying electromagnetic machine operation.

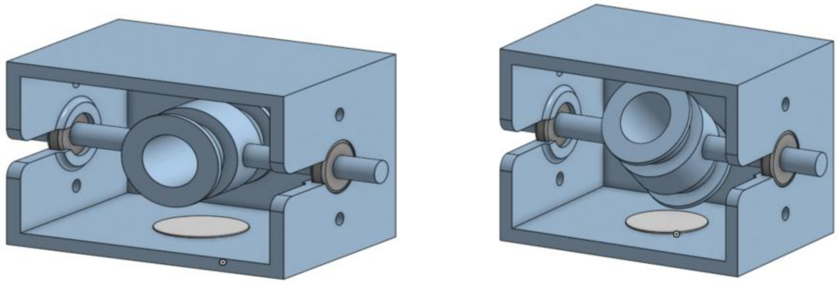

Figure 4**.** 3D model of the rotor–stator assembly of the LecXbit generator with dual-output (AC and DC) connections.

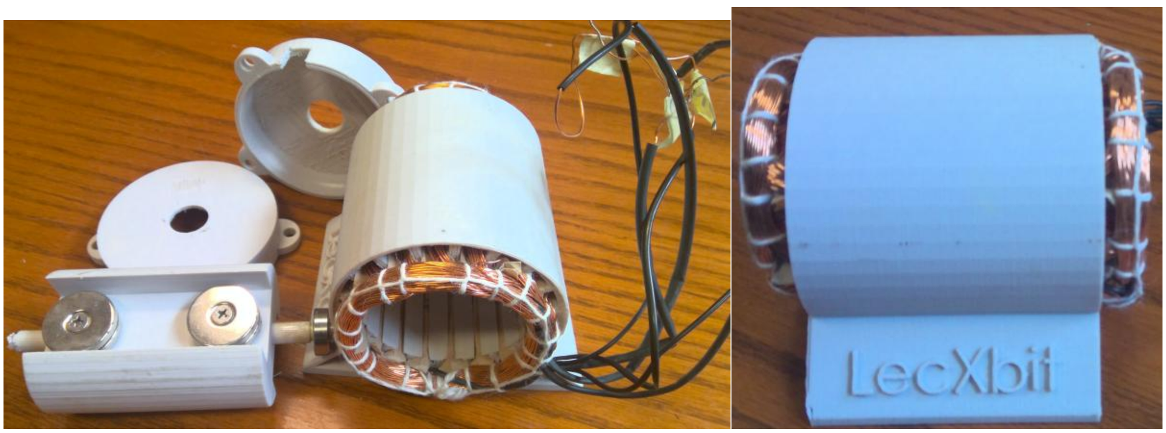

Figure 5. LecXbit three-phase AC system used to generate three-phase voltages and demonstrate three-phase machine operation.

5. Observations and Student Feedback

Preliminary feedback on LecXbit was collected during lecture through structured, in-class polling and discussion. After demonstrations, students were asked to reflect on their understanding of the concepts and indicate their level of agreement with statements such as whether the demonstration improved their conceptual clarity. Responses were gathered informally through hand-raising and follow-up discussion across two lecture sections with a total of 213 students.

While this feedback was not collected using a formal survey instrument and exact counts were not recorded, a clear majority of students consistently indicated that the demonstrations helped clarify abstract concepts and improved their ability to connect mathematical expressions with physical behavior. Qualitative comments also suggested increased engagement and improved intuition compared to traditional lecture formats. The instructor further observed higher levels of student participation and attentiveness during lectures incorporating live demonstrations.

These observations should be interpreted as preliminary and exploratory. More structured assessment methods, including controlled comparisons and formal data collection, are planned for future work to more rigorously evaluate the impact of LecXbit on student learning outcomes.

6. Conclusions

This paper presented LecXbit, a platform of low-cost, portable physical demonstration models designed for embedding electromagnetic and electric machine demonstrations directly into lecture settings. LecXbit addresses a persistent challenge in engineering education: helping students develop intuition for abstract, dynamic, and invisible electromagnetic phenomena while maintaining analytical rigor and classroom practicality.

Two classroom implementations were described, spanning a third-year energy systems course and a second-year introductory electromagnetics course. Across both contexts, LecXbit demonstrations allowed students to observe cause-and-effect relationships between magnetic flux variation, induced electrical responses, and mechanical behavior. Preliminary observations from classroom use suggest that lecture-embedded physical demonstrations, when used to complement traditional instruction, can support conceptual understanding, engagement, and confidence.

A key contribution of this work is the demonstration that effective physical models for lecture use can be designed to be safe, portable, and cost-effective without sacrificing conceptual clarity. By emphasizing transparency, modularity, and direct interaction, LecXbit provides a scalable approach that can be adopted across multiple courses and instructional contexts.

As a work-in-progress, this study focuses on design rationale and preliminary classroom evidence rather than large-scale statistical validation. Ongoing and future work will include broader deployment across additional course sections, refinement of assessment methods, and longitudinal evaluation of learning outcomes. The LecXbit platform offers a promising pathway for integrating experiential learning into traditionally abstract engineering courses while preserving the strengths of analytical instruction.

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