ADVANCING ELECTROMAGNETIC TRANSMISSION LINE KNOWLEDGE THROUGH EXPERIENTIAL LEARNING

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ABSTRACT

The complexity of teaching electromagnetics and transmission line analysis concepts presents significant challenges for 1-year long postgraduate taught (PGT) students, who often engage with the subject primarily through theoretical instruction. This paper examines the value of embedding non-assessed experiential learning opportunities to reinforce knowledge and build technical skills in transmission line theory, practical terminations, and radio frequency (RF) design. This intervention presents reflections on the effectiveness of experiential learning in reinforcing student knowledge and confidence. The success of this approach has been evaluated through indirect performance indicators, such as improvements in coursework performance, lab engagement levels, and qualitative feedback from instructors. This approach can be adopted by other Higher Education providers to enhance students' learning experience by incorporating practical activities that strengthen the connection between theory and practice.

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1 INTRODUCTION

Higher education institutions offering one-year master's programs face the challenge of delivering comprehensive subject knowledge in a condensed time frame. Many of these programs focus on theoretical understanding without incorporating practical hands-on opportunities beyond the individual research project. In engineering and applied sciences, this approach may result in superficial comprehension, limiting students' ability to translate theory into practice. This paper outlines an initiative to integrate non-assessed practical labs to complement theoretical learning. Therefore, the significance of hands-on experience in improving students' grasp of electromagnetic transmission lines, particularly in lossy and lossless modes with various terminations is highlighted.

The study is driven by three key research questions:

1. What are the challenges of upskilling students when teaching concepts purely through theoretical instruction?
2. Which pedagogical approaches effectively inspire students to engage with abstract electromagnetic principles?
3. How does experiential learning reinforce knowledge and improve comprehension of electromagnetics and transmission line analysis?

2 CONTEXT AND PRACTICAL WORK

2.1 Challenges when teaching purely theoretical concepts

Teaching purely theoretical concepts is a fundamental aspect of education across various disciplines, especially engineering. However, these concepts are often abstract and have limited immediate practical applications, which makes it difficult for students to grasp, retain, and apply their knowledge. This presents educators with distinct challenges, primarily due to the abstract nature of the material and students' difficulties in connecting theory to practical applications.

Theoretical concepts often lack immediate real-world connections, making them seem abstract and irrelevant to students. This disconnect can lead to reduced motivation and engagement (Mayer, 2020). Furthermore, abstract concepts require students to engage in high-level cognitive processing, which can impose a significant burden on students' cognitive resources. Cognitive Load Theory (CLT), described in (Sweller, 1988, 2011), presents that working memory has a limited capacity. Instruction that imposes an excessive cognitive load, particularly extraneous load (unnecessary cognitive demands), can hinder the learning of essential information (germane load). Therefore, abstract theoretical concepts, if poorly presented, can easily overload working memory. Baddeley (2012) provides a comprehensive overview of working memory, highlighting its crucial role in learning and comprehension. The limited capacity of working memory makes it challenging for students to simultaneously process and integrate multiple abstract ideas, which are often interconnected in theoretical frameworks. It is well noted that the development of abstract thinking depends on students' ability to handle theoretical concepts is related to their stage of cognitive development (Piaget, 1952).

Students may struggle to connect theoretical concepts to their personal experiences, future goals, or real-world applications. This lack of perceived relevance can lead to decreased motivation and engagement, hindering the learning process. Deci and Ryan (2000) Self-Determination Theory (SDT) emphasise the importance of autonomy, competence, and relatedness in fostering intrinsic motivation. When students perceive theoretical knowledge as irrelevant, it can undermine their sense of autonomy and competence, thereby reducing their intrinsic motivation to learn. Brown et al. (1989) introduced the concept of situated cognition, arguing that knowledge is context dependent. Theoretical concepts, when presented in a decontextualised manner, may lack meaning and relevance for students, making them less likely to engage with the material. Eccles and Wigfield (2002) developed the Expectancy-Value Theory, which suggests that students' motivation is influenced by their beliefs about their ability to succeed (expectancy) and the extent to which they value the learning task (value). If students do not value theoretical knowledge, they are less likely to invest the necessary effort to learn it.

Therefore, a significant challenge in teaching theoretical concepts is ensuring that students can transfer their knowledge to new and different situations. Theoretical knowledge is often intended to be generalisable, but students may struggle to apply it beyond the specific context in which it was learned. Bransford et al. (2000) emphasised the importance of deep conceptual understanding for effective knowledge transfer. If students possess only a superficial understanding of theoretical concepts, they will struggle to apply them in new contexts.

2.2 Pedagogical approaches in upskilling students

To address the challenges above, educators can employ a variety of pedagogical approaches designed to enhance students' understanding, motivation, and ability to transfer theoretical knowledge. Active learning strategies engage students in the learning process, promoting deeper understanding and retention of theoretical concepts compared to passive methods like traditional lectures. Madhuri et al. (2012) presents the use of inquiry-based learning, where students actively investigate questions, construct explanations, and test their ideas. This approach encourages critical thinking and problem-solving skills, which are essential for mastering theoretical knowledge. Barrows and Tamblyn (1980) demonstrated problem-based learning (PBL), in which students work collaboratively to solve authentic, ill-structured problems. PBL provides a context for applying theoretical concepts, making them more relevant and meaningful. Mazur (1997) demonstrated the effectiveness of peer instruction, a technique that involves students discussing conceptual questions with their peers. This approach promotes active engagement, clarifies misunderstandings, and fosters deeper understanding through articulation and debate.

Furthermore, visual representations can make abstract theoretical concepts more concrete and accessible, facilitating comprehension and retention. Ainsworth (2006) proposed the DeFT framework to learning, emphasising the importance of using multiple representations (e.g., diagrams, graphs, simulations, analogies) to support student learning. Different representations can highlight different aspects of a concept, catering to diverse learning styles and promoting a more robust understanding. Furthermore, interactive simulations can enhance students' understanding of dynamic

systems and abstract processes as reported in (Koh et al., 2010; Smith & Pollard, 1986), which develop a more intuitive grasp of theoretical relationships. Additionally, Novak and Gowin (1984) introduced concept mapping as a tool for organising and representing knowledge. Concept maps visually depict the relationships between concepts, helping students to structure their understanding of theoretical frameworks.

Consequently, connecting theoretical concepts to real-world applications and contexts can increase student motivation and facilitate the transfer of knowledge. For instance, context-based learning enhances student engagement and understanding by situating theoretical knowledge in relevant and meaningful practical implications as reported in (Avargil et al., 2012; Boud & Feletti, 2013). Further, literature reported in (Herreid & Schiller, 2013; Herreid, 1994) highlights the effectiveness of case studies in applying theoretical concepts to real-world scenarios. Analysing case studies allows students to see how theories are used to explain and solve complex problems. Additionally, in (de Los Rios et al., 2010; Krajcik & Shin, 2014; Mills & Treagust, 2003; Uziak, 2016) it has been demonstrated that project-based learning (PBL) can foster deep understanding and transfer of knowledge through authentic problem-solving. PBL provides opportunities for students to apply theoretical concepts in the context of extended, real-world projects. On the other hand, experiential learning reinforce knowledge and improve comprehension of engineering theoretical concepts as emphasised in (Hajshirmohammadi, 2017; Harrisberger, 1976; Jamison et al., 2022; Tembrevilla et al., 2024).

Finally, teaching students' metacognitive strategies such as planning, monitoring, and evaluating their learning can empower them to take control of their own learning, leading to improved understanding and retention of theoretical concepts as reported in (Tanner, 2012). Additionally, prompting students to self-explain their reasoning and adopt reflective practice can enhance their understanding of complex concepts and encourages them to actively process information and make connections between new material and their prior knowledge promoting critical thinking and the development of deeper understanding of concepts as reported by Chi et al. (1989) and Schön (2017).

Therefore, the presented literature review highlights the need for embedding immediate real-world connections within taught theoretical concepts to increase motivation. It is important that students recognise relevance in the programme and connect theoretical concepts to their personal experiences, future goals, or real-world applications. This work builds from the literature and addresses cultural and educational background gaps in one-year PGT programmes. The contribution is the effective implementation of various pedagogical approaches to promote modern methods to teaching theory. This is done by incorporating mixed active teaching techniques blending between interactive lectures, interactive workshops and experiential learning, which have bridged the gap between complex theories and practice enthusing students around the subject.

2.3 Description of the Intervention

The Electronic Communications Technologies course is a specialised, 15-credit, Level 6 postgraduate program taught at the School of Electrical and Electronic Engineering, University of Sheffield. It is primarily designed for students pursuing degrees in

electrical and electronic engineering, wireless communications, and aerospace engineering. Therefore, this course equips students with industry-relevant skills essential for designing high-frequency circuits and systems. Key topics include electromagnetic interference mechanisms, circuit design techniques, filtering, screening, transmission lines, S-parameters, Smith charts, equivalent circuits for passive and active devices, RF amplifier design, noise performance, and nonlinearities in RF circuits and systems.

The module learning outcomes are:

- Analyse the nature and scope of electromagnetic interference (EMI) in modern electronic and electrical systems
- Describe the broad principles of combating EMI both at the equipment design stage and during its testing, commissioning and use.
- Design circuits to control electromagnetic emissions and minimise EMI.
- Describe the different forms of transmission lines and understand high frequency transmission lines theory.
- Use Smith chart and "S" parameters to design transmission lines and RF circuits, and explain the terms used to specify linearity in power amplifiers.
- Employ the high frequency equivalent circuits of both passive and active devices to predict the devices' performance and make quantitative estimates of the noise performance of simple RF systems.

The course content is delivered through interactive practical driven in-person lectures that explore both the theoretical foundations and practical implications of each topic. To support student learning, a wide range of interactive materials—including quizzes, videos, course notes, and problem-solving exercises – are made available through the educational platform. While the course is highly specialised and theory-driven, students successfully develop technical knowledge and skills at various cognitive levels, from recall to design, in alignment with Bloom's taxonomy (Bloom et al., 1956). This is largely achieved through interactive lectures that incorporate real-life scenarios, case studies, simulations, and practical demonstrations using portable equipment.

Assessment is structured to evaluate both foundational understanding and higher-order problem-solving skills. Students are assessed through an end-of-semester exam and two coursework components. The exam follows an open-book format and consists of two stages:

1. **Stage 1:** A multiple-choice and calculation-based assessment, where students demonstrate their grasp of key concepts and achievement of course learning outcomes.

2. **Stage 2:** An open-ended evaluation with design-based questions, requiring students to apply their knowledge to real-world scenarios, showcasing their problem-solving, critical thinking, and decision-making abilities.

The coursework provides students with the opportunity to deepen their understanding by engaging in practical design tasks. Specifically, students explore matching network

design and electromagnetic compatibility challenges through case studies of their choice, fostering independent research and applied learning.

This teaching approach and assessment strategy ensure that students develop a strong conceptual foundation while acquiring industry-relevant knowledge and skills. However, the lack of hands-on practical activities presents challenges, particularly in the early stages of the course. Concepts such as electromagnetics and transmission line modelling can initially seem abstract due to their highly theoretical nature. This abstraction often hinders deeper comprehension and student engagement. To bridge this gap and enhance student understanding, a non-assessed experimental session was introduced. This session provided students with the opportunity to visualize and analyse the real-world behaviour of transmission lines under lossy conditions. By simulating practical scenarios, this initiative aimed to improve conceptual clarity and engagement with complex topics—an approach that will be further discussed in the following section.

2.4 Proposed Experiential Learning Model

To bridge the gap between theoretical understanding and hands-on competence in transmission line theory, a comprehensive practical intervention was implemented as part of the EEE6220 module. This intervention was designed to provide engineering PGT students with a robust experiential learning platform that simulates real-world signal transmission phenomena, reinforcing core theoretical concepts such as the attenuation constant (α), phase constant (β), and characteristic impedance (Z). At the heart of the intervention is a structured, inquiry-based laboratory sequence using the NI ELVIS II platform, a bespoke transmission line circuit board and data acquisition screen shown in Fig.1. Students engage with a series of progressive experiments; matched load, short circuit, and open circuit terminations, spanning frequencies from 1 kHz to 6 kHz. These configurations are deliberately chosen to simulate complex conditions found in telecommunications and signal processing networks. Through the systematic acquisition and analysis of voltage and phase data at different line sections, students calculate and graphically interpret α and β using linear regression techniques. This process demystifies the propagation characteristics of lossy transmission media and fosters a deep conceptual understanding of wave behaviour along lines.

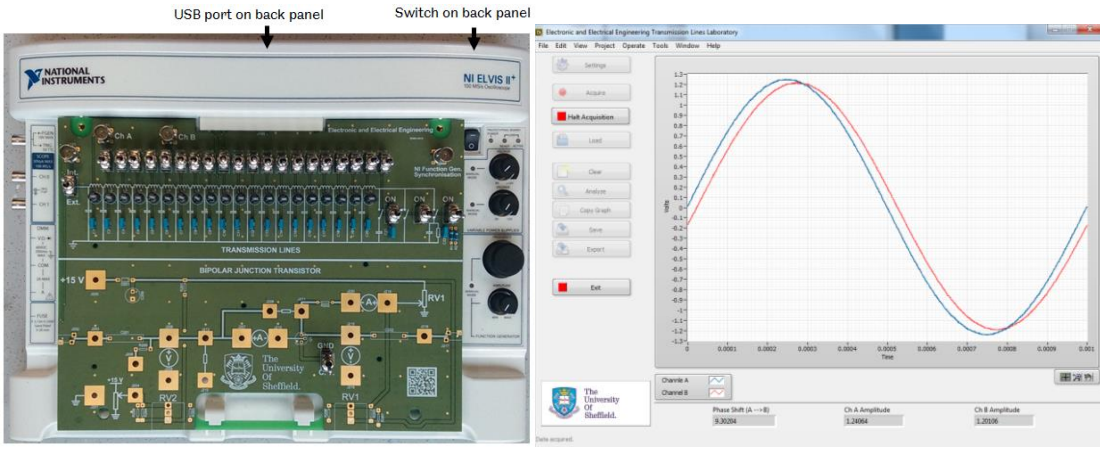

Figure 1: NI ELVIS platform with Transmission Lines lab board and data acquisition screen.

To prepare students effectively, the intervention mandates pre-lab calculations and a formative quiz, compelling learners to derive theoretical values for α, β and Z prior to experimentation. This pre-emptive activity primes students with contextual knowledge and creates a scaffold for reflective comparison with empirical results. The hands-on component requires PGT students to perform signal excitation via a function generator, observe outputs via an oscilloscope data acquisition and record phase shifts and amplitudes at incremental sections. Using this data, students convert attenuation values into Nepers and visualise voltage amplitude, attenuation and phase progression across the line. These tasks enhance skills in instrumentation, data logging, graphical analysis and critical evaluation of discrepancies between predicted and observed values. Furthermore, the intervention embeds engineering judgement and diagnostic reasoning, as students are prompted to evaluate the suitability of transmission lines for audio frequency applications and identify causes of voltage fluctuation, mismatches and phase distortion. The students are expected to articulate how improper terminations (open or short circuit) affect wave reflection and standing wave patterns skills essential for RF engineers and system designers. The intervention concludes with reflective analysis questions that compel students to synthesise their findings and critically assess limitations due to non-idealities, such as lumped element representation, finite board length and measurement uncertainty. This practical framework not only supports the development of technical and analytical skills but also cultivates professional behaviours aligned with EUR-ACE and AHEP learning outcomes, including safe laboratory practice, teamwork and effective communication of results. The structured pre-lab preparation, immersive hands-on experimentation and post-lab reflection form a complete learning cycle aimed at producing transmission line-literate postgraduates equipped to tackle contemporary engineering challenges. The students have given positive verbal feedback on how this experiment has consolidated their learning; for example few quotes are included here “The hands-on experience helped me to understand the theory fully, seeing the wave behaviour along the line made concepts of attenuation and phase shift much clearer, it helped me understand where and why transmission line theory actually matters in real application, comparing theoretical results with experiment helped me consolidate the maths behind transmission lines, using the NI ELVIS setup felt like working with real industry equipment, I feel more confident now on transmission line theory concepts”.

3 EVALUATION OF THIS APPROACH

The integration of experiential learning in teaching electromagnetic transmission line theory has proven highly effective in enhancing MSc students' technical skills, comprehension, and confidence. Many students, particularly those from overseas with strong mathematical backgrounds, often lack practical technical experience. The hands-on experimental sessions, using the NI ELVIS II platform, supported students to bridge the gap between theoretical learning and real-world applications, fostering skills in instrumentation, data logging, and analytical reasoning.

Furthermore, the proposed teaching method significantly improved students’ practical skills, such as using lab equipment and conducting data analysis, which are essential for RF design and telecommunications. By applying theoretical concepts like attenuation, phase shift, and impedance to real-world experiments, students gained deeper insights and better prepared themselves for future industry challenges.

Furthermore, students reported enjoying the interactive lectures and hands-on experience offered only in this module among their degree programmes. They also reported increased confidence in both their technical abilities and their understanding of complex electromagnetic concepts. Working with professional-grade equipment made the material more accessible and relevant, boosting students' self-assurance in applying their knowledge and developing critical thinking skills. This has also reflected on students' coursework and exam outcomes as the module has seen zero fail rate since 3 years implementation of the interactive teaching method and experiential learning sessions. The ability to relate theoretical knowledge to practical outcomes strengthened their exam responses, particularly in design-based questions that required application of key concepts. While these results are promising, wider adoption requires consideration of transferability. Other Higher Education providers can embed practical activities aligned with theory, using accessible lab equipment or simulations tools. Similar interactive sessions could be implemented in modules such as electromagnetism, circuit design, or control systems, even with varying resources. Scalable solutions like low-cost kits or remote labs can further support implementation across diverse institutions.

4 CONCLUSIONS

Upskilling students in purely theoretical concepts presents significant challenges, primarily related to the abstract nature of the material, its perceived lack of relevance, and the difficulty of transferring knowledge. However, educators can employ a range of effective pedagogical approaches to address these challenges. Active learning, visualisation, contextualisation, and metacognitive strategies can promote deeper understanding, enhance student motivation, and facilitate the transfer of theoretical knowledge to real-world applications. Future research should continue to explore and refine these pedagogical approaches, particularly in the context of specific disciplines and diverse student populations and investigate the use of emerging technologies to support the teaching of abstract concepts.

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