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Enhanced Antenna Technology-Based Teaching: A Blended Learning

Rawad Asfour[a], Rola Saad[a,1], Salam K. Khamas[a],

[a]School of Electronic and Electrical Engineering, University of Sheffield,

ABSTRACT

In today's educational landscape, adopting constructive pedagogical strategies is imperative to foster students' comprehension and involvement in challenging subjects such as electromagnetics (EM). This paper introduces a blended educational model that harmoniously combines the Flipped Classroom and Simulation-Aided Learning models, tailored for a technology-centric teaching of antennas. The Flipped Classroom paradigm empowers students to absorb content autonomously outside the class, allocating class time for immersive discussions and hands-on activities. Concurrently, Simulation-Aided Learning offers a tactile approach to grasping the complexities of antenna geometries and characteristics through simulations. Computer Simulation Technology (CST) Microwave Studio was elected for implementing the simulation component due to its intuitive interface and expedited learning trajectory, rendering it particularly advantageous for novices. Through this blended approach, students are provided with a more comprehensive and practical understanding of antenna theory and design technologies, which is crucial for fostering skills necessary in the ever-evolving field of wireless communications.

KEYWORDS

Electromagnetics teaching, flipped class, interactive learning, simulation-aided teaching.

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Introduction

Antenna teaching in higher education represents a challenge due to the abstract contents and the intensive advanced mathematics. As a result, this is usually one of the least popular topics that students avoid if they have a choice. This is true for junior and senior level students as the reputation of complexity propagates to the final year and MSc projects that involve antenna theory. This is not surprising as such projects usually involve a steep learning curve within a limited allocated time and

[1] Corresponding Author : Rola Saad, r.saad@sheffield.ac.uk,School of Electronic and Electrical Engineering, University of Sheffield, Sheffield S1 3JD, UK

other assignments and exams that students must attend. These challenges are combined with another problem of a reduced allocated time to electromagnetics modules in many universities worldwide. Based on a comprehensive literature review conducted by the authors, and summarized in Figure 1, numerous studies have been published over the last few decades to address the declining students' interest and engagement with electromagnetics-related topics, which captured a considerably increased interest since the pandemic outbreak. Most of the reported studies propose innovative and effective teaching methodologies that increase the students' engagement with introductory and advanced electromagnetics. These initiatives took advantage of the significant growth of technology, personal computers, and devices.

One of the most used approaches in achieving engaging and effective EM teaching is software-aided teaching that has been employed either by developing customized software or utilizing a software package. The earliest attempts were based on utilizing various tools such as the mini numerical electromagnetics code "MININEC" to visualize the electromagnetic fields as well as gaining design experience of basic wire antenna geometries (Cole et al, 1990; Excell, 1993). In addition, several software tools were developed under the activities funded by the NSF/IEEE Center for Computer Applications in Electromagnetic Education (CAEME) (Iskander,1993; de los Santos Vidal et al, 1996; Fabrega, Sanz, Iskander, 1998) . Furthermore, a numerical EM field solver with a graphical user interface was used to teach introductory EM using an application-based approach (Beker, Bailey, Cokkinides, 1998).

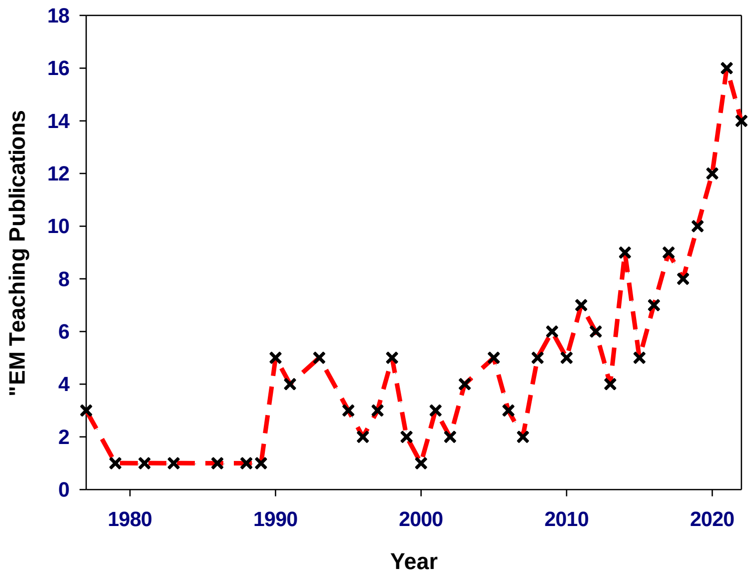

Figure 1. A non-inclusive number of yearly published articles that are focused on EM and antenna teaching.

The importance of multi-media-based EM and antenna teaching was discussed in (Iskander, 2002), where a virtual antenna laboratory was introduced. Teaching electromagnetics using mathematical packages such as Mathematica and MATLAB were adopted in (Anderson, Mina, 2003). In addition, using CAD tools to assess undergraduate students' understanding was proposed (Popovic, Giannacopoulos, 2005). A customized tool was developed based on the finite element method (FEM) for interactive learning of electromagnetics to elementary-level students (Trlep, M. et al, 2006). A stronger students' retention of electromagnetics was observed when adopting technology-enabled active learning (TEAL) compared to traditional teaching formats (Dori et al. 2007). On the other hand, several virtual tools were developed and used to reach the right balance between EM theory and computer simulations (Sevgi, 2008). The importance of EM teaching using field visualization was demonstrated by employing COMSOL (Talele, 2014). Besides, the significance of virtual tools in teaching electromagnetics has been discussed in (Mukhopadhyay, Gupta, 2008; Sevgi, 2015). In addition, a hybrid teaching approach that involves traditional lectures and hybrid labs was adopted (Ferreira et al, 2017).

Alternative approaches have been reported to enhance the students' understanding through a complet 3D visualization of the electromagnetic fields (Christopher et al, 2018; González-Carvajal, Mumcu, 2020; Tan, Heh, 2019). A full and partial flipped-classroom model was adopted at several universities, where recorded lecture videos are made available to students before the in-person lecture that can be focused on interactive learning or other engaging activities (Hoole, et al, 2015; Berger, 2017; Stickel, 2020; Notaroš et al, 2019; Furse, Ziegenfuss, 2020). For example, the flipped-class model provided additional time for students to learn and develop code in Finite Elements (FE) optimization in a one-semester course at Michigan State University (Hoole, et al, 2015). An innovative project-based learning approach was proposed in (Baker, 1997), where students were asked to design a practical antenna with a different design topic every academic year. This approach inspired additional studies on project-based learning (Lumori, Kim, 2010; Venkataraman, 2009; Aydın, Kalayci, 2016; Yu, Cheng, Barik 2020). However, project-based learning may requires considerably more teaching hours (Yu, Cheng, Barik 2020). and a laboratory space, which is not always an option and depends strongly on the whole curriculum. An alternative approach to enhance student engagement was proposed by incorporating design, simulation, and laboratory sessions in the course besides the traditional lectures (Bunting, Cheville, 2009; Crilly, 2014; Ülker, 2020; Espinosa et al, 2020). A different approach was followed, using complex multi-step problems to enhance students' understanding (Leppavirta, Kettunen, Sihvola, 2011). Furthermore, utilizing software with a well-designed graphical user interface (GUI) for a complete virtual antenna design experience is essential. Although students will not have the opportunity to develop their code, considerable teaching time and effort will be saved, which helps students focus on the antenna design instead of programming. In addition, learning the required technique, such as the method of moment (MoM), Finite Difference Time Domain (FDTD), Finite Elements (FEM), etc, represents a challenge on its own merits that may need to be taught in a separate dedicated module. Furthermore, based on the authors' experience, when students develop their software, this may improve their programming skills more than deepen their understanding of the required physical concepts. Moreover, since software packages are widely used in the industry, developing an experience with such tools adds additional in-demand transferable skills for any graduate.

This review shows that sometimes, relying on a single teaching method may not considerably enhance students' knowledge and learning. The pedagogical approach is governed by several factors, such as the subject, available resources, the allocated teaching hours, students' backgrounds, expectations, and the higher education market demands. Therefore, a flexible, customized approach that utilizes an efficient blend of teaching techniques is more suitable for a particular course than others. Furthermore, adopting a technology-based learning approach is most suited to the current generation of technology-driven students and supports the skills gap shortage in the industry. Therefore, this study proposes a blended approach combining two learning models: the Flipped Classroom approach and the simulations-aided learning method. The former is usually combined with interactive learning, and the latter is based on utilizing an electromagnetic simulation tool that is efficiently adapted to be delivered in a series of workshops.

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Table 1 : Detailed learning plan and activities

Session	Instructor's activity and support	Student activity
Week 1	1. Video recording: Introduction to Antennas 2. Video recording: Maxwell's equations Lecture: Recap of the topic and quizzes	1. Read articles on Antenna History (5-10 minutes) Watch the Videos and revise the handouts
Week 2	1. Video recording: Antenna fundamentals#1 2. Video recording: Antenna Fundamentals#2 Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts Attempt the relevant tutorial questions
Week 3	1. Recorded video: Antenna Fundamentals#3 2. Recorded video: Antenna Fundamentals#4 Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts 2. Attempt the relevant tutorial questions Think of various antenna's matching techniques
Week 4	1. Recorded video: Antenna Fundamentals#5 2. Recorded video: Antenna Fundamentals#6 Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts 2. Attempt the relevant tutorial questions Visualize the dipole far field using Excel.
Week 5	1. Recorded video: Wire Antennas: Electrically Small **Dipole Antenna** 2. Recorded video: Wire Antennas: Resonant **Dipole Antenna** Lecture: Recap of the topic and quizzes	1. Attempt the relevant tutorial questions Compare the radiation efficiencies of small dipole and loop antennas
	Introduction to CST simulations	CST simulations of dipole antenna
Week 6	1. Recorded video: Wire Antennas: Small **Loop Antenna** 2. Recorded video: Wire Antennas: Resonant **Loop Antenna** Lecture: Recap of the topic and quizzes	**1.** Watch the Videos and revise the handouts. Attempt the relevant tutorial questions
Week 7	1. Recorded video: Wire Antennas above ground planes Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts Attempt the relevant tutorial questions
	CST simulations	CST simulations of loop and monopole antennas
Week 8	1. Recorded video: Slot Antennas 2. Recorded video: Aperture Antennas Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts 2. Attempt the relevant tutorial questions Think about the duality theorem.
	CST simulations	CST simulations of slot antennas
Week 9	1. Recorded video: Microstrip Antennas#1 2. Recorded video: Microstrip Antennas#2 Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts 2. Attempt the relevant tutorial questions What is meant by surface waves?
	CST simulations	CST simulations of microstrip antennas
Week 10	1. Recorded video: Antenna Arrays#1 2. Recorded video: Antenna Arrays#2 3. Recorded video: Antenna Arrays#3 Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts Attempt the relevant tutorial questions
	CST Simulations	CST simulations of linear arrays
Week 11	1. Recorded video: Antenna Arrays#4 2. Recorded video: Antenna Arrays#4 Mutual coupling Lecture: Recap of the topic and quizzes	1. Watch the Videos and revise the handouts Attempt the relevant tutorial questions
	CST Simulations	CST simulations of phased arrays

Colour Codes

Accquisiton
Investigation
Discussion

Teaching Model

To benefit the most from utilizing combined teaching methodologies, the weekly teaching sessions require a degree of synchronization between the topics delivered in the lecture and simulation sessions. The antenna module is delivered in 18 timetabled in-person teaching sessions, each lasting 50 minutes, over one semester. The in-person sessions are divided between interactive lectures and simulation-based workshops carefully tailored to implement a blended teaching method characterized by flipped classroom and software-based learning as demonstrated in the weekly learning schedule of Table 1. As shown in Figure 2, the pedagogical framework includes a set of synchronous and asynchronous learning activities making use of recorded videos, course handouts, and interactive quizzes all tailored to educate students on the topic, encourage their curiosity to learn, and support their understanding when attending the interactive lectures and hands-on simulation-based workshops. Traditional lectures are transformed into synchronous interactive sessions and feature a flipped learning approach where students watch pre-recorded videos before attending the lectures, offering opportunities to reflect on their learning and ask questions. The mathematical content, which introduces Maxwell's equations, is delivered in a 50 minutes introductory lecture. In later lectures, students learn how these equations determine the radiation from a point source and infinitesimal dipole antennas. Detailed derivatives and proofs are kept to a minimum, and the teaching time is utilized more effectively to deepen the student's understanding of how to apply design principles to various practical antenna types relative to real-world applications. Students' knowledge developed as they practiced and applied their skills to analyze and evaluate antenna design-related problems. They focused on the design equations for each basic antenna type and how they can be utilized effectively through quizzes, examples in the handouts, and problem-solving tutorial sheets. Additionally, students are provided with valuable virtual prototyping experience and aspects likely needed in practical scenarios utilizing 3D visualization of various basic antenna geometries and radiated fields. The content release and interactive lectures are carefully aligned with scaffolded hands-on software-based learning interactive workshops delivered over six sessions, as detailed in section II.B. A flow chart of the utilized teaching model is illustrated in Figure 2.

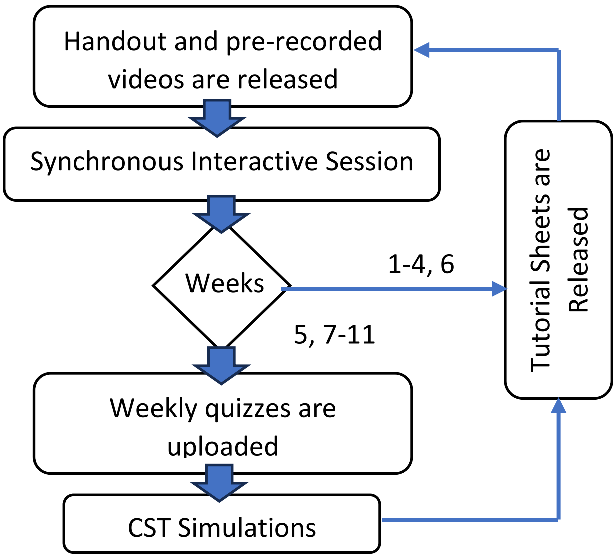


Figure 2 : The utilized teaching model

A. Flipped-Classroom Teaching

1. Asynchronous Learning

For asynchronous learning, the recorded videos mainly follow a traditional antenna teaching approach to explain the fundamental theory and the design and operation of basic antenna types. The weekly teaching material for each topic starts by releasing the relevant handout and pre-recorded videos before the scheduled lecture. In total, 9 hours of prerecorded videos were released with an average of 50 minutes per week. These resources are uploaded to the Blackboard (BB) platform and made accessible to students according to the module's teaching plan. This allows students to learn the topic and attend the class well-prepared. In addition, the weekly released handouts are focused on fundamental theory with a focus on the physical meaning of the equations and the impacts of various parameters. Understanding, rather than memorizing, these equations provide students with the knowledge to fully interpret the simulation results. Therefore, simulations have been used to complement the fundamental theory. Each handout is associated with a problem-solving tutorial sheet designed to help students gain the required depth of theoretical foundation.

Releasing learning materials on a weekly basis offers several benefits, including preventing students from feeling overwhelmed by a large volume of content, thereby enhancing their engagement and focus. This method also enables students to absorb and apply knowledge gradually, reducing the likelihood of bypassing foundational concepts in favour of more advanced topics. Additionally, it helps maintain student participation in discussions, activities, and assignments each week. Moreover, it provides instructors with the flexibility to update or adjust content based on recent developments or the specific needs of the class.

2. Synchronous Sessions

Each synchronous, in-person session includes a pre-cap of the relevant pre-recorded videos and interactive learning through focused anonymous multiple-choice questions (MCQs) quizzes. The quizzes cover the concepts of the weekly topic, engage students to reflect on their understanding, offer instantaneous feedback to reinforce learning and provide instantaneous clarification of any conceptual misunderstanding through further discussion and relevant examples. Each question lasts 60 seconds and is delivered using an application that students can download on any electronic device, whether in class or off-campus, as the interactive quizzes aim to enhance the students' learning rather than to assess them. To promote engagement, students' responses were anonymous, and it was made clear that no marks are awarded as the primary purpose of these quizzes is to gauge their understanding. A total of 120 conceptional MCQs covering topics ranging from Maxwell's equation to phased arrays were delivered over 12 lectures. After each synchronous session, the relevant quizzes were uploaded to the Blackboard platform with a multiple-attempts option for revision and practice purposes at the student's own time and pace. In addition, feedback is given on Blackboard to explain where a student went wrong. An example of a quiz is illustrated in Figure 3, where the image was captured at the end of the 60 seconds question time. Hence, the correct answer is highlighted. In addition, the percentage of students who made the right choice is also shown. The example of Figure 3 is for a question that requires simple calculations using only one of the fundamental equations. Figure 4 presents a screen capture image of the same quiz when uploaded to BB, where it can be noted that a feedback comment is added that appears on the screen if a student chooses the wrong answer.

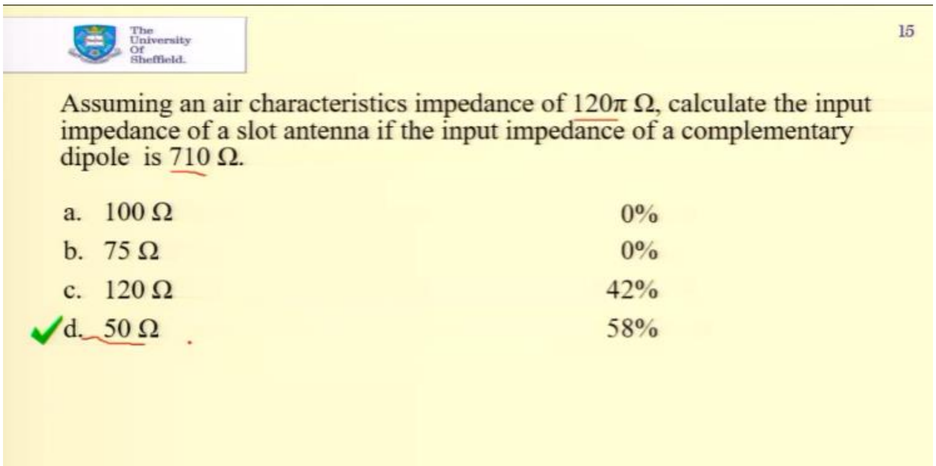


Figure 3 : Screen captured slide at the end of a 60 second question from the in-person lecture that shows the percentage of responses for each choice.

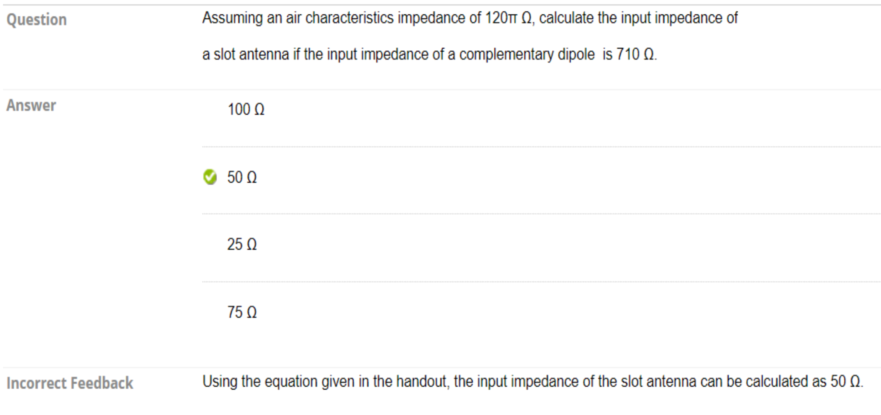


Figure 4 : Screen captured image of the above quiz when uploaded onto Blackboard for practice purposes.

Table 2 presents data that demonstrate the students' engagement with accessing the weekly quizzes on Blackboard over the last three years. The 1st year of this course, the entire module was delivered online, including the quizzes. The following year, hybrid teaching was adopted, where students studied on-campus or remotely. All students were on campus in the 3rd year of delivering the module. This background may explain the notable improvement in the students' engagement as the module delivery moved gradually from online to in-person weekly lectures. Another point that can be observed is the declined engagement towards the end of the semester, which is expected due to the exam preparation and other assignment deadlines. It is important to note that, for each antenna type, the synchronous session is followed by a software simulation session focused on the same topic before moving to another antenna geometry.

Table 2 : Number of times quizzes were accessed over 3 years of running the module

Topic	Quizzes Access		
	1st year (online)	2nd year (hybrid)	3rd year (on campus)
Introduction	25	76	95
Antenna Parameters #1	29	57	90
Antenna Parameters #2	21	70	106
Antenna Parameters #3	16	52	112
Dipole Antenna	24	61	86
Loop Antenna	15	47	88
Monopole Antenna	18	37	62
Aperture Antenna	16	37	59
Microstrip Antenna	19	23	65
Antenna Arrays	16	29	63
Total	100	483	825

B. Simulation-Based Teaching

Each simulation session was strategically scheduled immediately following the corresponding in-person lecture. This ensures that simulation complements the learned theory while still fresh in the students' minds. Figure 5 illustrates the CST hands-on session structure. The session starts with a 10-minute Instructor-Led overview of the antenna type to be analyzed and its fundamental theoretical concepts. The instructor then provides students with the design specifications. Students work in small groups or individually and use the freely downloaded students' version of the software to create the required virtual antenna geometry for 20 minutes. This is where teacher's role shifts to a mentor and facilitator, offering guidance as needed while allowing students to explore, problem-solve, and troubleshoot on their own. After completing the simulation, students spent 10 minutes discussing and analyzing the designed antenna performance. This includes comprehensively examining return losses, gain, directivity, polarization, efficiency, and radiation pattern. Here, the teacher adopts a reflective and inquiry-based posture, prompting students to critically examine their results and draw meaningful conclusions. They check if the chosen simulation designs correlate with those outlined in the handouts using design equations to bridge the theoretical and simulation aspects. This process includes a meticulous comparison of simulated results with calculated values in the last 10 minutes, thereby fostering critical thinking and analytical skills among students. The teacher acts as a moderator ensuring students develop deeper conceptual understanding. It should be noted that the full edition of the software is also available on the university network for students to access at any time.

Over several weeks, the educational program progresses into the meticulous design of antennas to explore various configurations. The initial week focused on designing a dipole antenna and developing a loop antenna in the subsequent week. The following weeks feature simulation sessions, each focused on one of the following antenna types: monopole, aperture, and patch antenna. The final session concludes with creating a 4-element array antenna. Figure 6 illustrates a detailed representation of a sample antenna created using CST Microwave Studio. In addition to virtually modelling antennas, as in Figure 6, several physical antenna prototypes were showcased during the relevant session, as shown in Figure 7. Students welcomed this approach as it allowed them to visualize manufactured antenna prototypes.

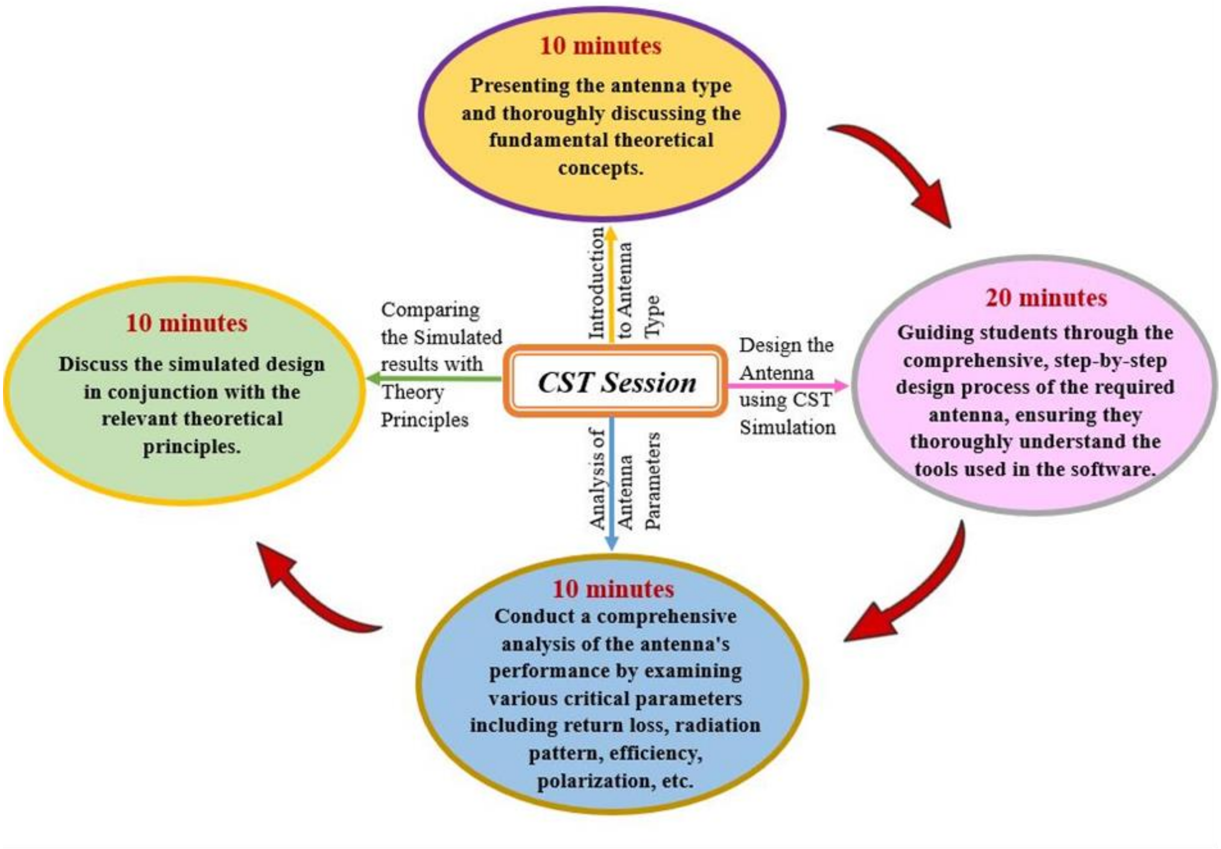
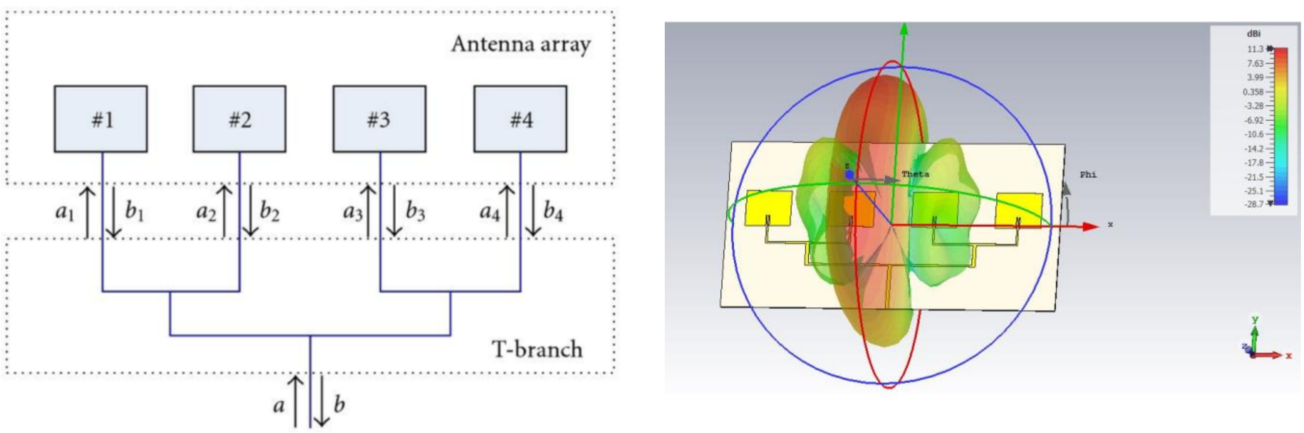


Figure 5 : Structure of the CST hands-on sessions.



(a) (b)

Figure 6 : Example of 4 elements array taught in a simulation session: (a) Layout, (b) Radiation pattern

Figure 7 : Antenna prototypes that students observed during the sessions

Throughout this comprehensive teaching model, students were tasked with the dynamic challenge of modifying antenna dimensions or adjusting the array's feed network. This provided a unique opportunity for students to apply theoretical knowledge gained in lectures and anticipate the practical implications of their design modifications. The outcome was a more profound comprehension of antennas and matching techniques, typically reserved for more advanced instruction levels, and the cultivation of invaluable transferable skills in antenna simulations and teamwork. This pedagogical approach effectively addressed the challenge of teaching complex electromagnetic concepts and equipped students with practical skills and knowledge essential for their future careers.

C. Assessment

The module is evaluated at the end of the semester through a formal examination comprising two parts. The first part is an online assessment featuring multiple-choice questions that involve conceptual as well as calculation-based questions designed to assess the achievement of learning outcomes. These questions follow the same style and format of the quizzes of synchronous sessions and are conducted on the Blackboard platform. This test is a must-pass test and accounts to 50% of the total exam mark. The second part is a traditional paper-based exam that includes more complex and in-depth analytical questions, focusing on theoretical concepts and design principles, also contributing 50% to the final exam score. This examination format is standard across all the Department of Electronic and Electrical Engineering modules at the University of Sheffield.

Evaluation of Teaching Model

Students were invited to respond to an ethically approved questionnaire to assess the blended teaching approach upon completing the module. The survey was structured to evaluate to what extent this teaching approach is effective, and engaging, has added value to students' knowledge and informed their career choices. For the 2023-2024 academic year, 100 students were registered for this module, and all survey received a 30% response rate. The survey was structured around 3 main areas: evaluation of experiences with the asynchronous learning material, synchronous lectures, and CST sessions. In addition, it assessed students' perception of the module overall, their wider understanding, the challenges, and if they valued the different feedback received throughout the course duration.

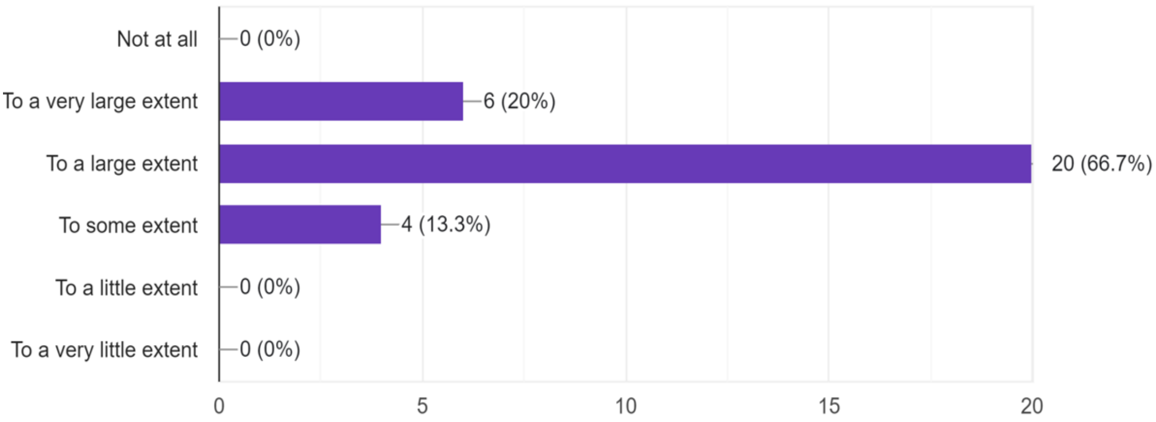


Figure 8. Student response to the question: "To what extent did you find the pre-recorded videos informative?"

A. Students' Experience with Asynchronous Contents

Ahead of asynchronous learning activities, students were equipped with tasks to do such as reading material and, most importantly, specific recorded videos that introduced the theory and aimed to give students enough time to learn the basics and, therefore, facilitate the live lectures and hands-on sessions to be interactive and more engaging. Therefore, students were surveyed on the value of the recorded videos and whether they were informative. 20% of students responded "to a very large extent", 66.7% of students responded; "to a large extent", and 13.3% of students responded "to some extent" leading to a total of 86.7% of students responding positively, as shown in Figure 8. This was reassuring that the recorded videos are useful and of added value to the teaching model taking a flipped learning and blended model approach.

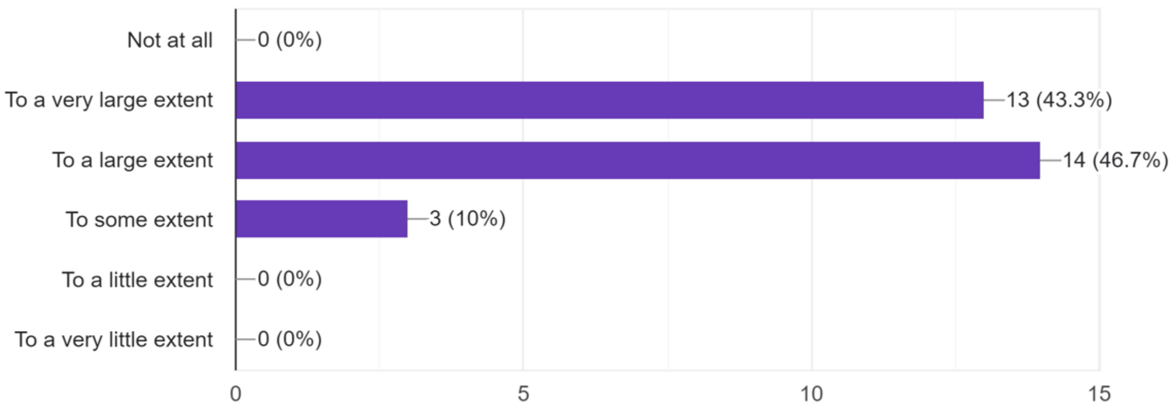


Figure 9. Students' response to the question: "To what extent did you find the live lectures interactive?"

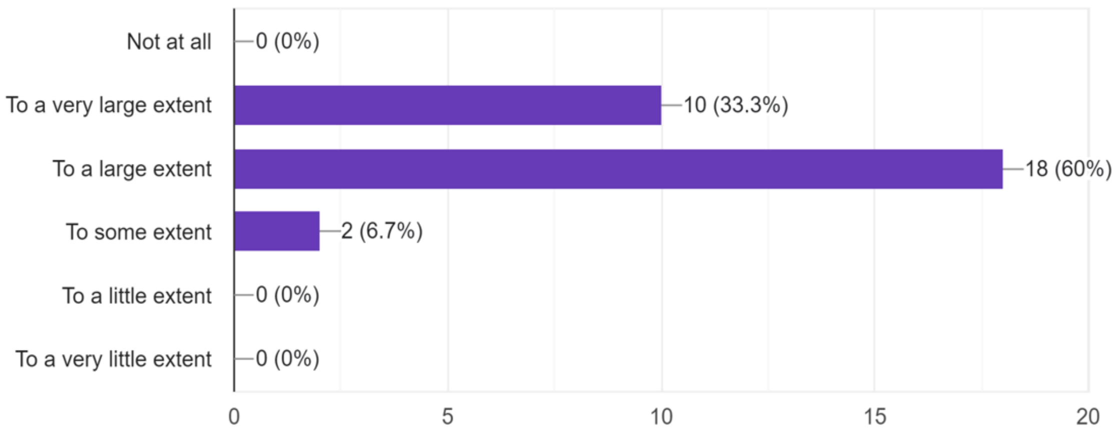


Figure 10. Students' response to the question: "Instant feedback after the in-class quizzes enhanced my learning experience?"

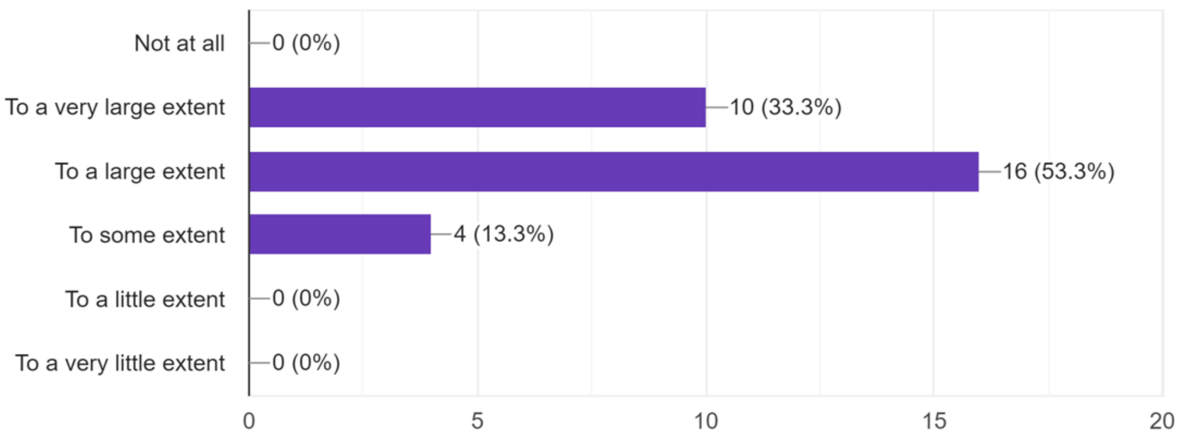


Figure 11. Students' response to the question: "To what extent did you find the CST demonstration sessions engaging?"

B. Students' Experience with Synchronous Content

Following a set of asynchronous activities, students attend lectures using a modern interactive and research-led style. When questioned on whether the live lectures were interactive, 43.3% of students responded "to a very large extent" 46.7% responded "to a large extent", and 10% responded "to some extent", leading to a total of 90% of students responding positively, as shown in Figure 9. The in-person lectures offered an opportunity to assess students' knowledge through interactive quizzes informally. Students had the opportunity to reflect on their understanding of the content and receive timely feedback. Therefore, students were surveyed on how valuable the feedback received through the live quizzes was to improve their learning experience. 93.3% of students responded positively and acknowledged the value of the feedback received through interactive quizzes. In comparison, 6.7% responded "to some extent", as shown in Figure 10. This was reassuring and evidenced throughout the course by the students' continuous engagement and high attendance rates.

C. Students' Perspective on CST Workshop Sessions

As mentioned earlier, hands-on CST demonstration sessions reinforce the asynchronous activities and interactive in-person lectures, taking students to higher levels of learning to apply and analyze antenna design principles, as per Bloom's taxonomy model (Sawin,1957). Students were surveyed on their experience with the engagement level of the CST sessions; 33.3% of students responded, "to a very large extent", 53.3% responded "to a large extent", 13.3% responded "to some extent", leading to a total of 86.6 % satisfaction rates, as shown in Figure 11.

Students were also asked a further two reflection questions:

1. "Can you comment on what is the most useful or engaging part of the CST demonstration sessions?"

Some of the responses included:

- "You can follow the instructor's demonstration step by step to complete your own project, which is very fulfilling!"
- "Help me to have a deeper understanding"
- "High interactivity", "The way to design antenna"
- "It makes me realize how to use and connect with theory"
- "It can be used in the real work, many jobs needs it."

2. "What knowledge or skills did you gain from CST antenna visual prototyping?"

Some of the responses included:

- "Design skill and knowledge"
- "How to model a desired antenna and make further adjustments to it"
- "I became able to imagine how the radiation going to be by just seeing the shape of the antenna"
- "Deepened the understanding of the antenna"
- "Theory into practice"

Reflecting on the above two responses to questions 1 and 2, it is evident that students understood and appreciated the purpose, value and extent of the hands-on practical CST sessions to develop their knowledge, consolidate theory, and enhance their technical and transferrable skills to use an industry relevant software such as CST. This encouraging outcome led us to inquire further about students' overall experience with this blended pedagogical approach as discussed in the next two sections.

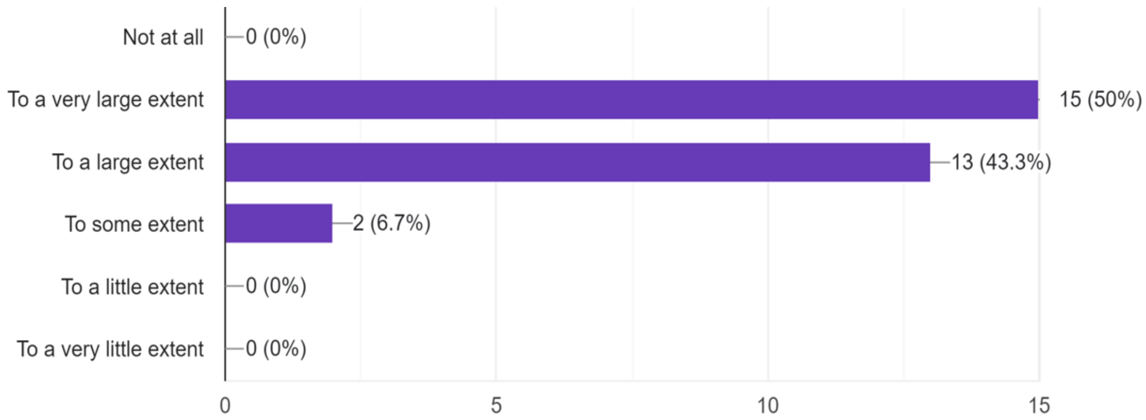


Figure 12. Students' response to the question: "The handouts, tutorial sheets and quizzes collectively provided me with the required knowledge to fully interpret the results of antenna CST simulations."

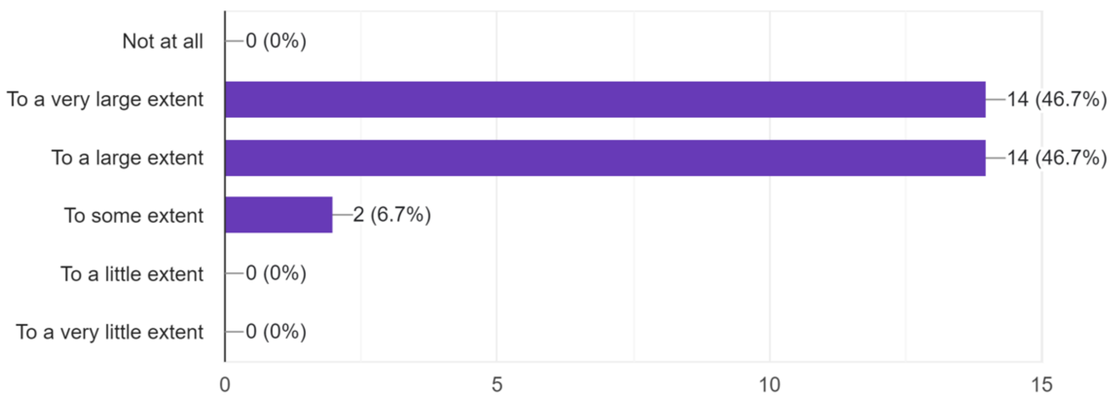


Figure 13. Students' response to the question: "My understanding of electromagnetic concepts improved after taking the EEE6223 module?"

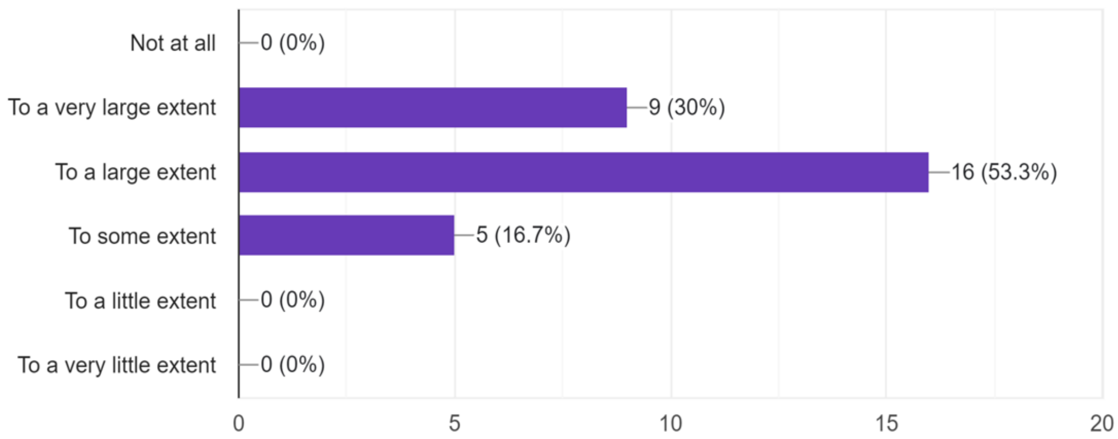


Figure 14. Students' response to the question: "This module has positively changed my perspective of RF antenna design challenges and requirements.

D. Student perspective on the blended pedagogical framework

Having engaged with asynchronous activities and attended live lectures, and CST workshops, students' views on their blended learning experience demonstrated a 93.3% overall satisfaction rate, with 50% of students responding "to a very large extent", 43.3% responding "to a large extent", and 6.7% responding "to some extent" reflecting on the usefulness of asynchronous material to support their essential knowledge and understanding to interpreting CST simulations design outputs, as shown in Figure 12. While 93.4% of students reported that their knowledge of electromagnetic concepts has improved after taking the antenna module, as shown in Figure 13.

Students were also asked a further question to reflect on the effectiveness of this blended teaching model.

1. How can you describe the teaching method used in teaching electromagnetics and antennas? Is it effective? And in what way from your point of view?

Some of the students' responses are shown below:

- "Yes, I like the way of understanding the concepts more than focusing on equations and derivations"
- "yeah it was effective and I gained a lot knowledge"
- "Lecture on the course content, with trivia questions inserted to test mastery of what has just been explained. It is effective. I wish the teacher would add some demonstrations of logical derivation of definitions and theorems and be able to take the students through a little bit of handwritten derivation, which would be more helpful for understanding."
- "Some of the students cannot bring their own laptops or their laptops do not support the software. I think it would be much better if we can have a computer room for CST."
- "To fast to follow, once skip one step, I cannot catch up."
- "Need to be improved on the examples given in the lectures. Maybe by cutting down the amount of the examples and extending more on each example."

These responses gave insights into the effectiveness of the teaching model and the challenges that need to be addressed. First, students showed awareness of the effectiveness level, offering an in-depth and practical understanding of antenna design and modelling. However, on the other hand, some students struggled with accessibility issues, especially around not using a computer room for CST workshops, and time spent explaining each antenna design case study and the speed of delivery of practical demonstrations, which gives us room for improvement on realistic challenges of this nature and most importantly offering structured guidance to accommodate students learning needs and diversity.

E. Students' Reflections and Overall Experience on the Module

Two survey questions in Figures 13 and 14 demonstrate students' overall satisfaction with the module. For example, 83.3% of students responded positively, reporting "to a very large extent" and "to a large extent" when asked if the module has changed their perspective on RF antenna design requirements and challenges, in comparison to 16.7% responding "to some extent", as demonstrated in Figure 14. While 93.3% of students responded positively reporting "to a very large extent" and "to a large extent" when asked if they would recommend this module to other students, in comparison to 6.7% responding "to some extent", as demonstrated in Figure 15.

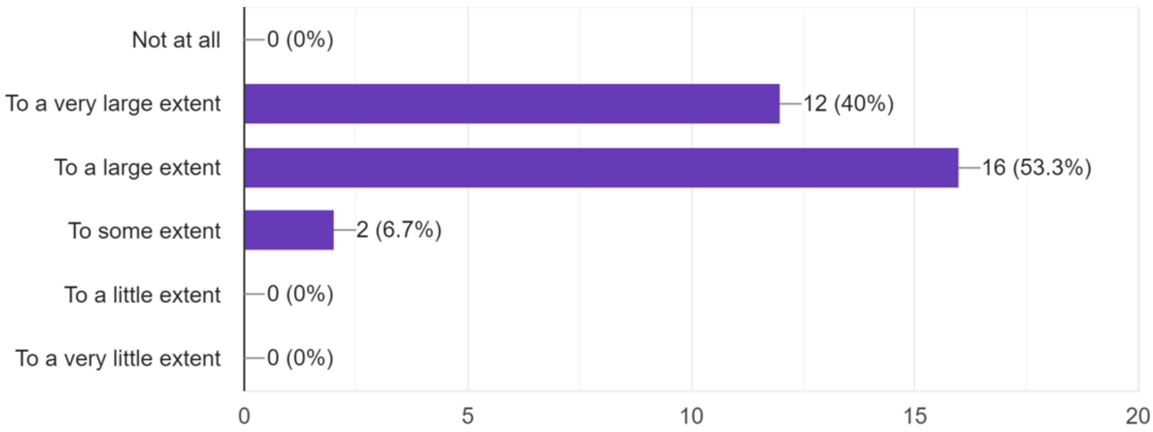


Figure 15. Students' response to the question: "Now having studied this module, to what extent are you most likely to recommend this to other students?"

To elaborate on students' satisfaction with the module overall and how this compares against other modules they have undertaken within their study so far, students were asked four reflective questions as follows:

1. "How do you assess the difficulty level of the module?"

Some of the responses included:

- "Hard but exciting"
- "A little difficult that I have to memorize a lot of new knowledge."
- "It is not that difficult but a feel there are too many topics"

2. "What are the most challenging aspects of the module?"

Some of the responses included:

- "The diversity of topics"
- "knowing the physical meaning of formula"
- "Some theorems and calculations are difficult to understand."
- "Understand different kinds of antennas and their functions."

3. "What are the most enjoyable aspects of the module?"

Some of the responses included:

- "Open discussions"
- "Interactive learning"
- "I have learned the use of the new software."
- "designs and simulations"
- "Know how antenna work"

4. "How do you compare your experience with this antenna module to other MSc modules that you have undertaken?"

Some of the responses included:

- "My job is to test antennas; this course helps me to understand antennas better."
- "I feel more confident in this module more"
- "More interesting"
- "Understand concepts more clearly"
- "this module is hard and teachers try their best to let us understand the module"
- "From my point of view, it maybe connect physical theory more and make me realize the wireless communication system from the different perspective ie physics perspective. Thank you so much. This module is a golden studying experience for me. Thank you so much."
- "Most difficult and enjoyable at the same time"

Reflecting on students' responses to questions 1 and 2, we could observe that students have found the module challenging, which is anticipated electromagnetic topics being the hardest to grasp with analysis based on Maxwell's equations and requiring a high level of competency from individuals either a 3D memory or strong background in Mathematics and Physics. The students' comment, "Hard but exciting", is what we anticipated the module would look like after the blended teaching approach, having utilized online tools and CST to simplify concepts and put theory into practice, while the fact that the topic can be challenging cannot be eliminated completely. On the other hand, reflecting on students' responses to question 3, students have enjoyed the open discussions, the interactive learning model, developing knowledge in antenna design, and learning how to use new software.

When comparing the antenna module to other modules, as in question 4, students reported increased confidence, interest, and enjoyment in learning new concepts. Students also appreciated the opportunity to connect theory to practice and offer specialized knowledge to apply in the workplace. Nevertheless, some students find the theory and practice on antennas harder than other topics, which is also understandable given that students learn differently and naturally have different interests in diverse subjects that match their abilities.

Conclusions

This work reported a novel approach integrating flipped classroom learning with software-based learning in an interactive model that bridges the gap between theory and practice. It offers opportunities for students to embrace learning new skills while developing essential theoretical and technical knowledge around antenna theory and design principles. Students' overall learning experience has been improved due to the careful design of synchronous and asynchronous learning activities that reinforced learning, as reported from observing students' responses to ethically approved survey questions designed to capture students' views.

The success of the proposed approach has been demonstrated through the presented evaluation, the annual departmental module feedback, and, most importantly, the increased number of students selecting MSc and PhD projects focused on antennas after completing this course. A partial transferability of this approach has already been achieved by adapting the flipped classroom and interactive learning techniques to another module on digital communications principles, with plans to integrate Simulink for future simulations. Additionally, the CST simulation sessions could be further enhanced by introducing a mini-design project, such as designing a phased array, over four sessions.

This project should be preceded by two introductory sessions on the simulation software. Besides, the quizzes incorrect answers feedback can be enhanced further by pointing students to the right formula or section. In another aspect, the teacher's role shifts from a traditional approach in delivering theoretical content to a more facilitative role in interactive learning. This progression further evolves into that of a mentor and collaborator during the computer simulation sessions. This transformation highlights a dynamic, engaging learning environment where students are empowered to take charge of their learning, while the teacher adopts a supportive and adaptive role.

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