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Teaching undergraduate students to think like real-world systems engineers: A technology-based hybrid learning approach

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Abstract

A hybrid teaching approach that relied on combining Project Based Learning with Team Based Learning was developed in an engineering module during the past 5 years. Our motivation was to expose students to real-world authentic engineering problems and to steer them away from the classical banking approach, with a view to developing their systems engineering skills via collaborative learning. Our third year module was called Team Design and Project Skills and was concerned with 320 students dividing themselves in teams to develop a smart electronics system. We reveal module design details and discuss the effectiveness of our teaching approach via analysis of student grades during the past 5 years, as well as data from surveys that were completed by 68 students. 64% of surveyed students agreed that the module helped broaden their perspective in electronic systems design. Moreover, 84% recognized that this module was a valuable component in their degree programme. Adopting this approach in an engineering curriculum enabled students to integrate knowledge in areas that included control systems, image processing, embedded systems, sensors, as well as team working, decision making, trouble shooting and project planning.

KEYWORDS
active learning, electronic systems design

1 | INTRODUCTION

The nature, complexity and type of problems that practicing engineers are required to solve are different from the classical text book problems that students are exposed to, since real-world problems are often ill-bounded and not well defined. Such problems require interdisciplinary knowledge and multiple solutions may exist, or no solutions at all.[1] Moreover, engineers in the real-world typically solve problems in teams. Rarely do engineers work in solitude and collaboration is therefore necessary.[2]

There has been an ongoing dialogue between academia, accreditation bodies and industry regarding the range of technical and interpersonal skills required from graduating engineers to meet the needs of the continuously shifting job market. According to the literature, engineers lack the necessary team working, communication, social and emotional graduate attributes needed in today's job market.[3] Therefore, engineering accreditation bodies now require universities to demonstrate that their students have enough opportunities to develop these skills during their engineering studies. To achieve the above objectives, the attributes of Team-Based Learning (TBL) with

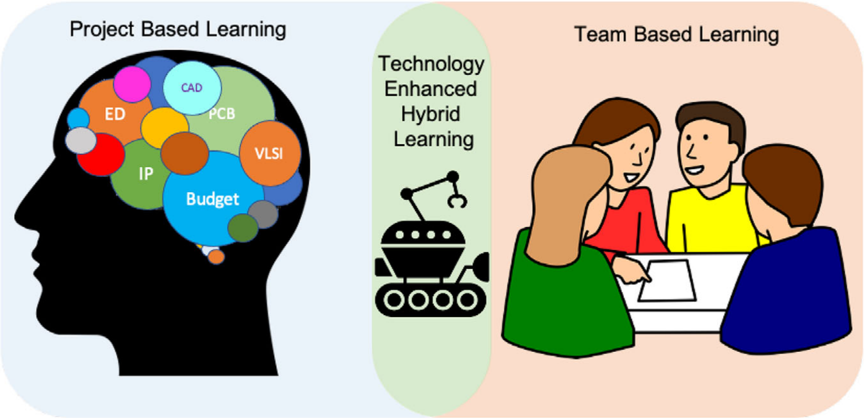

FIGURE 1 Concept of the proposed hybrid learning technique, which combines the elements of Project Based Learning (PBL) with Team Based Learning (TBL) via a technology enhanced learning activity.

Problem Based Learning (PrBL) were combined in a module, such that students 'learn' teamwork, collaboration, project management and communication as by products of the activity within the module (as show in Figure 1). Instead of being taught these interpersonal skills, our approach relied on getting absorbed by a technology enabled challenge that makes them forget the time and effort spent on developing them. Therefore, students were given an opportunity to develop both interdisciplinary systems engineering knowledge as well as their interpersonal skills in a single module.

Furthermore, active learning techniques have demonstrated improved student understanding of engineering concepts.[4,5] Instead of the traditional teacher-centered instruction approach, our motivation was to encourage more modules to adopt a student-centered learning, such that students can re-use their skills across a range of different modules.[6] In fact, the strategy adopted in this investigation involved optimizing student learning using a varied or systemic approach that fits well with real-world engineering practices.[7] Such innovative teaching approaches are necessary, since it simply becomes infeasible to cover the rapidly evolving electronic engineering field in a typical 4-year undergraduate programme. Therefore, optimized student learning becomes essential.

2 | RESEARCH CONTEXT

Project Based Learning (PBL) is a student-centered teaching strategy that has proven to improve student performance. It focuses on practical, real world problems that aim to increase student motivation. Typically, PBL involves splitting students into groups of 6 to 10 students to work on a project that is facilitated by a single instructor for 6 to 10 weeks. Student groups are then shuffled to tackle another project.[8,9] There are numerous examples of PBL adopted in electronic engineering disciplines for enhancing student learning and embedding soft skills.[10–17] A thorough review of PBL is available by Kokotsaki et al.[8] Evaluations of these interventions have focused almost exclusively on student interviews or responses to open-ended questions, which have found that students are in favor of courses that implement PBL in engineering programmes.

Most recently, Salankar et al. investigated the impact of PBL on the performance of engineering students[18] using the OCEAN (Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism) personality model.[19] Based on surveys that were completed by 77 students, Openness and Extraversion were personality traits that were significantly improved. Furthermore, the use of PBL in a robotics course was investigated by Calvo et al. [15] While the study provided a thorough description of the PBL activity, there was brief insight into how student satisfaction was measured, how the surveys were conducted nor the instruments used to conduct their investigation. There was also no mention of the percentage of students who took part in the surveys (response rate). Student satisfaction was measured using two surveys that elicited information about the teaching method, workload and course interest. However, a small sample size was used in each of the 4 years (8 to 38) and student choices were limited to only four. Similarly, the authors in the literature[20] investigated student satisfaction for a PBL activity in a third year power electronics course. Their course consisted of 60 class hours and 90 h of independent learning. The PBL activity accounted for 65 h, which were divided into 26 class hours and 39 h of personal and group work. Students carried out the project in small groups of three. The course was assessed via an exam weighing 25% of their final grade, in addition to a design review (65%) and a grade for attitude and participation (10%). Again, student results were analyzed using only nine questions, with no mention of the sample size, nor the number of students who took the survey.

Similarly, TBL is another collaborative student centered teaching method, which was initially used for business teaching. Students are typically divided into groups of five to seven students to work on a project throughout the duration of a module. Unlike PBL, students are divided into teams of five to seven people and are all facilitated by a single instructor.[21–23] This is particularly advantageous in situations where faculty resources are limited and faculty members are required to supervise a growing number of students. Introductory pre-reading is required before each class in TBL, which is tested via two 'readiness' tests. The first is an individual test, which is often a series of Multiple Choice Questions (MCQs), followed by a team test consisting of the same MCQs.[24] The motivation behind issuing the same MCQs to the teams is to promote team discussions. Subsequently, the last phase in the TBL activity involves issuing a team problem or task.

However, each of these active learning techniques have their challenges in practically implementing them.[25] In the case of TBL, developing multiple individual and team assessments before each class is time consuming. Furthermore, managing 320 students that are divided into 40-50 teams by a single instructor is simply infeasible. Moreover, for the effective implementation of PBL, developing a variety of engaging group projects in a single module is a technically demanding task for the instructors. Therefore, a combination of active learning techniques may be necessary, where multiple instructors are involved in coordinating teams of students who are given a single project to complete by the end of a course. This hybrid learning approach was suggested by Burgess et al. in a medical curriculum, when a PrBL learning activity was converted to TBL and authors recommended a 'hybrid [learning] approach utilizing the strengths of both methods'.[24] In fact, Dolmans et al. proposed a fusion between TBL and PrBL[26] to optimize student learning in a medical curriculum. Similar to the medical profession, electronic engineering has witnessed a rapid transformation since the early invention of the transistor in 1947. Faced with this rapidly growing discipline, engineers must deal with uncertainty, incomplete data and a host of engineering problems with varying complexity.

While the differences between PBL and PrBL are indeed very subtle, a decision was made to combine the best aspects of PBL with TBL. According to the literature, the main difference between PrBL and PBL is the deliverable that students submit to demonstrate their attainment of a set of learning outcomes.[27] With PrBL, students are expected to develop a solution to a problem, whereas with PBL students are expected to deliver an entire product, service or process. Therefore, PBL is better suited to the environment that engineers typically work in. Furthermore, PrBL has its limitations in engineering education. Engineers must be able to use the knowledge gained from exposure to problems in their engineering education to be able to solve real world problems outside university.[28,29] However, every problem will be different. Consequently, it may not be useful as an engineering practice to acquire knowledge that can be used and applied in practice. Moreover, since engineering education is hierarchical in nature, PrBL cannot be used to fill in missing gaps of knowledge. A detailed discussion regarding the differences between problem and PBL for engineering education is available in the literature.[30]

In summary, the main difference between PBL and TBL lies in the nature of the task that students undertake. PBL focuses on a practical, real-world problem, usually in the form of a project, that students work on for a period of 6 to 10 weeks, in groups of six to ten students. In contrast, TBL is centered on a module that involves a range of tasks or problems that students work on throughout the module. Additionally, TBL involves smaller teams of five to seven students who are all facilitated by a single instructor. TBL includes individual pre-reading before each class, which is tested via individual and team readiness tests, followed by a team problem or task. While both approaches are student-centered and collaborative, PBL allows for more depth and immersion in a real-world problem, while TBL promotes continuous learning and critical thinking. Therefore, our hypothesis is that a hybrid approach using the strengths of both methods could provide the best of both worlds.

Consequently, since active learning has proven to effectively improve student learning, we designed a module that mixes both TBL and PBL, which can be effectively delivered to large student cohorts. Our goal was to expose students to real-world authentic engineering problems, to increase overall student satisfaction and to develop their interpersonal skills as well as broad multidisciplinary knowledge. Our module was called Team Design and Project Skills (TDPS), which was delivered in the third year of an electronic engineering programme. From our previous investigations, we compared student experiences from two different countries (UK and China) and found similarities in terms of appreciation for the work and satisfaction.[31] Indeed, there were unpleasant feelings regarding student contributions to the group project, which led us to investigate the impact of Electronic Laboratory Notebooks (ELNs) on student learning and collaboration.[32,33] Our main findings from this previous work demonstrated that ELNs helped students better organize their work, which reduced the amount of time and effort required to complete the tasks. They also led to enhanced collaboration between group members, allowing them to share information and work more efficiently. We also noticed that ELNs helped ensure that all group members were contributing equally to the project. By documenting each individual's contributions and progress, ELNs enabled students to be accountable for their work and discourage free-riding.

Our current work goes beyond existing literature in combining the best aspects of PBL and TBL in a single module that meets a variety of the UK's Institution of Engineering and Technology (IET) graduate attributes, as evidenced from Table 1. We describe our approach in developing this module, how the tasks were aligned with accreditation body requirements, as well as student learning experiences during the past 5 years.

In the next section, the intended learning outcomes (ILOs) and the assessment methods are described. Next, the methodology for designing the open questionnaires to test student understanding and satisfaction are explained. In section 5, student responses to the questionnaires are presented. Finally, concluding remarks and recommendations are provided in the final section of the paper.

3 | MODULE DESIGN

As previously mentioned, real world engineering problems are often ill-bounded and ideal solutions do not exist. Moreover, the success of an engineering product is often determined by how well it achieves a budget and whether it was delivered on time.[2] Thus, given a predefined budget, students in our module were encouraged to develop their own unique solutions. In fact, students were required to solve a variety of problems in this module. Among the 11 types of workplace engineering problems that have been identified by Johansen,[34] the TDPS module aimed to expose students to the following types of problems:

1. Decision making – choosing between a limited range of alternatives.
2. Troubleshooting – identifying possible faults in the hardware or software.

TABLE 1 Graduate attributes and their mapping to the TDPS module.

IET Graduate Attributes	TDPS Module Activity
Understanding of, and the ability to apply, an integrated or systems approach to solving engineering problems.	Students are expected to divide the system into component parts, with each team member taking responsibility for the analysis of each subsystem.
Plan and manage the design process, including cost drivers, and evaluate outcomes.	Students are expected to manage the cost of the project and detailed design processes as a team, and are required to give a final oral presentation evaluating their final design. Students must manage the detailed design processes as a team, and are required to give a final oral presentation evaluating their design
Investigate and define the problem, identifying any constraints including environmental and sustainability limitations; consent, health, safety, security and risk issues; intellectual property; codes of practice and standards.	Students working on the smart rover are expected to carry out their designs based on constraints discussed with other team members, within an overall budget, and (since the currents are moderately high) consider health and safety implications.
Knowledge and understanding of the scientific principles underpinning relevant current technologies, and their evolution.	Practical knowledge of digital and analogue electronics, circuit theory and design.
Ability to apply quantitative methods in order to understand the performance of systems and components.	Students analyze the performance of their robots quantitatively and refine their design accordingly.
Ability to apply an integrated or systems approach to engineering problems through know-how of the relevant technologies and their application.	Practical implementation of basic electronics, programming, fault finding and testing.
Apply problem-solving skills, technical knowledge and understanding to create or adapt design solutions that are fit for purpose.	Students are expected to design and fabricate a fully functional electronic system using their knowledge of microelectronics, embedded processors, power electronics, computer programming and other areas. Students must engineer their design solution without relying on their instructors.
Manage the design process, including cost drivers, and evaluate outcomes.	Students are required to manage the design and implementation of a product under a fixed budget.
Work with information that may be incomplete or uncertain and be aware that this may affect the design.	Uncertainty and variation are inherent in the design exercise. For example, there are intrinsic variations in the motors, batteries and electronics used by students to drive their autonomous vehicles. Students must therefore measure and judge the magnitude of these variations, and design with these uncertainties in mind. Students are not provided with detailed instructions for building their rovers. They must work in teams using incomplete information to design rovers that meet certain criteria.
Demonstrate the ability to generate an innovative design for products, systems, components or processes to fulfil new needs.	Practical experience in analogue and digital circuit design, and micro-controller code, requiring innovative solutions to novel problems, with the challenge changing each year.
Awareness of relevant legal requirements governing engineering activities, including personnel, health and safety, intellectual property rights, product safety and liability issues	Students are expected to respect copyrights and other intellectual property. Students must also be aware of health and safety issues during fabrication of circuits with significant drive currents (fusing issues)
Communicate their work to technical and non-technical audiences.	Students will demonstrate these via an oral presentation, a lab report and two written technical reports.
Knowledge of management techniques that may be used to achieve engineering objectives.	Project management tools such as Gantt and PERT charts as well as to explore the design cycle model. Students also have to complete the project within given budget, and sub-teams have to comply with internal deadlines to deliver the objectives of the project on time
Understanding of and ability to use relevant materials, equipment, tools, processes, or products.	Students must program software, use tools and various electronics products to assemble a smart rover
Ability to use and apply information from technical literature.	Students must carefully examine data sheets and technical literature before purchasing and integrating equipment, which is required for designing and implementing a robotic product.
Ability to use appropriate codes of practice and industry standards.	Students learn to use equipment that meets industry standards.
Understanding of the use of technical literature and other information sources	Extensive use of technical data sheets, including parsing of key information to make component choice decisions
Awareness of team roles and the ability to work as a member of an engineering team.	Students must work in a team to achieve the desired results. They learn how to divide activities and achieve deliverables within a specific time-frame

3. Planning – defining a management structure and plan for the team.
4. Design – developing a rover that achieves these tasks.

Furthermore, the TDPS module was worth 10 credits with an expected student workload of 100 h at the undergraduate 3rd year level. In brief, the ILOs of the module were:

- To adopt a 'systems engineering' approach for the design and implementation of an electronic or technology-related product.
- To take full responsibility for the complete project lifecycle, without relying on the instructor.
- To gain and develop collaboration, management and leadership skills, as well as oral and written communication skills.

The learning activity involved developing a smart rover that can accomplish a set of communications, sensing and imaging tasks. Moreover, students were given a predefined budget (RMB1000) and a specific time-frame to complete the project (17 weeks). Students were asked to divide themselves into teams of six to eight people.

The module activities were designed to meet a diverse range of IET graduate attributes, as shown in Table 1. Among the essential attributes that students must attain is the ability to "work with information that may be incomplete or uncertain and be aware that this may affect the design".

Before the start of the module, a detailed module handbook was provided to the students and was uploaded on the university's virtual learning environment (VLE), which was Moodle. The handbook contained detailed instructions regarding the task descriptions, the assessment mechanisms, the mark schemes and the assessment deadlines. In addition, the implementation guidelines (the rules) were provided. A mixture of interim and summative assessments were used to ensure student progress. There was no examination component in this module. This was to focus entirely on TBL and PBL. We also aimed to develop assessments that are similar and authentic to real-world engineering deliverables. Details regarding the five different summative assessments designed for this module are described below:

- Lab Notebook – This was used as an interim assessment to carefully monitor individual student progress. ELN submissions were encouraged, since these enabled students and their instructors to monitor progress effectively, as described in our previous investigations.[33] They also facilitated student collaboration and the identification of problems that could hinder progress. Notebooks were assessed according to their organization, technical content, quality of analysis and interpretation of results. Notebooks were assessed in week 8 of the module and weighed 10% of the final grade. Students were given a variety of commercial and non-commercial software packages to choose from, which included LabArchives, RSpace and OneNote, SciNote, Benchling and elabFTW.
- Live Demonstration – Practical live demonstration to evaluate and test the rover's performance during week 17 of the module. The live demonstration weighed 15% of the final grade. Each team was given an opportunity to complete three technical tasks within a 12 min time frame. Each task carried a maximum of 10 marks. Students were subsequently penalized by one mark for every external interference, repositioning or restarting of their rovers.
- Oral Presentation – Instructors examined students to verify that the specifications have been met and to assess individual student contributions. Each team was allocated 35 min to present their work and students were evaluated according to the technical content of the presentation, quality of delivery, response to questions, structure of the presentation and quality of the slides. This component weighed 25% of the grade.
- Team Report – Final documentation report, which weighed 25% of the final grade. The report should explain the design, experimentation, testing and implementation of the technical product. Reports were assessed according to five criteria, which were 'technical content', 'presentation', 'organization', depth of literature survey and quality of writing.
- Individual Reflection Report – Report that highlights individual student contributions to the project. This report weighed 25% of the final grade and the assessment criteria used were similar to the group report.

Similar to the investigations by Conde[35] and Riley,[36] students chose their own team members and assigned a Project Leader, who was responsible for managing the team and for sharing their Electronic Lab Notebook (ELN) with the entire team.

As previously mentioned, our aim was to move away from traditional lecture-based teaching that relies on the banking approach, which primarily focuses on 'depositing knowledge in the minds of the learner'.[37,38] This teaching approach has been criticized in the literature since it leaves learners with few opportunities to engage with the learning materials and to develop their own skills. It also leaves them with even fewer opportunities to appreciate the interconnection or mapping between multiple courses. Consequently, during course design, we aimed to ensure that our course has many transferable aspects with other courses in the electronic engineering programme, as shown from Figure 2.

Consequently, during the first 2 weeks of the course, students attended only six 45-min lectures, which covered three topics: "Principles of Design", "Working with Data" and "Teamwork". During these lectures, we discussed Dieter Ram's "Ten Principles of Good Design" as well as the engineering design process. We also discussed "Teamwork", where we discussed the characteristics of effective teams and the stages of team development. Finally, we discussed the ICT tools to facilitate teamwork and collaboration. For example, we introduced the general concepts of ELNs and gave students the option of using them instead of traditional paper-based notebooks (PBNs). The assessments and their mark schemes were also explained to all students during the first introductory lecture.

In the next section, the methods used to evaluate the effectiveness of the TDPS module are described.

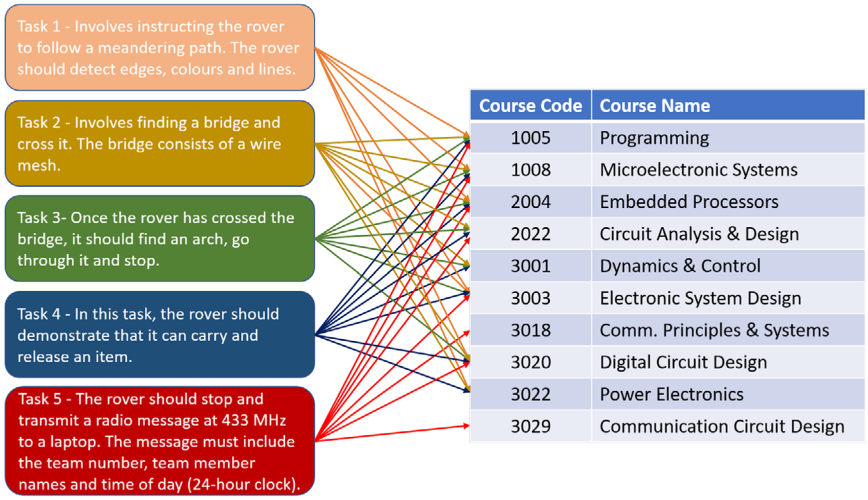

FIGURE 2 Technical tasks and their mapping to current modules offered in collaboration between our Scottish university and our partner university in China. These modules are taught in the first, second and third years of the Electronic Engineering degree programme.

4 | METHODOLOGY

4.1 | Participants

For the 2018/2019 academic year, 320 students enrolled in the TDPS module. The student cohort consisted of 74% males and 26% females. Due to the size of our student cohort and the duration of our module (17 weeks), it was not feasible to use either the TBL or PBL methods alone, so a combination of both was necessary. Therefore, we devised an approach that incorporated the strengths of both techniques. Consequently, we compromised by dividing the cohort into teams of eight, resulting in 40 teams that were almost evenly distributed among the three instructors. The course coordinator mentored 14 groups, while the other two instructors mentored 13 groups each. In addition to monitoring student progress via the ELNs, each of these convenors was also responsible for scheduling bi-weekly meetings with their teams for at least 30 min to ensure that any technical or logistical issues are handled in a timely manner. All teams were required to complete five assessments and the weighting of these assessments was previously mentioned in the module design section. Online surveys were administered to students in week 17 of the module to collect student feedback.

4.2 | Procedures

The module was designed to enable students to acquire a set of technical and interpersonal skills as by products of the activities within the module. The technical tasks involved detecting colors, edges, lines, following a meandering path, carrying an item as well as transmitting a radio signal. These tasks were distributed within the patio of our partner university in China, as shown in Figure 3. The five technical tasks and how these are mapped to other modules in the overall programme are shown in Figure 2.[39] These tasks were explicitly mentioned in the course's handbook, which was issued to students at the start of the module. In summary, the tasks for the rover project included instructing it to follow a colored path, finding and crossing a wire mesh bridge, going through an arch, releasing fish food into a lake through patio railings, and transmitting a radio signal with team information and the time of day.

Similar to the methodology adopted in literature,[40] we evaluated the effectiveness of the module by gathering participant consent prior to undertaking this study. Students were informed that their participation was completely voluntary and that all collected information would be anonymous and confidential. They were also informed that they were able to withdraw their participation at any time.

4.3 | Questionnaire design

Given the lack of research on this technology-enabled hybrid learning approach, we designed a questionnaire to gather student feedback regarding the effectiveness of this teaching approach. We therefore obtained the necessary consent approvals from our College of Science and Engineering to distribute online surveys that consisted of 22 questions. These questions were divided into four sections, as shown in Table 2. The first 10 questions in Section 2 were designed to collect valuable student opinions regarding the overall quality of the module. Students were invited to indicate their learning experience via a 6-point Likert scale ranging from 0 (Disagree Entirely) to 5 (Agree Entirely).[41,42] We preferred a 6-point scale to prevent students from giving "neutral" answers and to avoid student fatigue.[43]

Section 3 of the questionnaire consisted of three questions, which were concerned with obtaining feedback regarding the assessments used during the module. Section 4 consisted of five questions, which aimed to gather student feedback regarding their teamwork experience. Finally, Section 5 of the questionnaire consisted of four questions, which were concerned with understanding how well the module met its ILOs.

4.4 | Data analysis

A total of 68 out of 320 students took part in our online survey, who provided useful feedback and recommendations. The response rate

FIGURE 3 Track used for training of student rovers within the campus of our partner university in China.

was 21.25%, which easily surpassed the 8% response rate deemed acceptable for a class size of 300 for a 10% sampling error and 80% confidence level.[44] Students participated voluntarily and were told that their participation had no impact on their scores. There was no obligation for them to take part in the survey. Moreover, we preferred not to offer financial incentives to students to avoid respondents who are only participating for the incentive. Despite such incentives showing increased response rates, as reported by literature,[45] we did not offer financial incentives since we are aware that responses may be biased due to some individuals being more motivated by financial incentives than others, as reported by literature.[46] A detailed analysis of the results obtained from these surveys is presented in the next section.

5 | RESULTS AND DISCUSSION

By the end of the module, students were required to develop autonomously driven rovers that accomplished a certain set of tasks. Sample images of the rovers are shown in Figure 4. Results from the student responses to the questionnaires are shown in Figures 5 to 9. We will present and discuss these results according to the four survey question sections.

5.1 | Section 2 results - overall module quality

According to the survey results presented in Figure 5, 59% of students agreed that the module's level of difficulty was appropriate for a third year module. None entirely disagreed. An area for further support and improvement could be in the number of contact hours of formal instruction. In their opinion, only 6 h of lectures appeared insufficient, as shown in the results for Q3. However, our purpose was to move away from traditional lecture based instruction and towards independent learning. Perhaps this is attributed to the cultural background of our students. To remedy this problem, we propose more breakout or tutorial sessions for students to discuss their problems. We will also trial the use of technology, such as Piazza to enable greater interaction with students.[47]

When asked whether this module helped improve their analytical and problem solving skills (Q4), 75% of students either agreed, or strongly agreed. This clearly demonstrates that this module encouraged students to develop problem solving skills, enabling them to be better prepared for the real workplace.

5.2 | Section 3 results - quality of the assessments

Moreover, almost 31% of students strongly agreed that this module broadened their interest in other fields of study (Q6). When asked for further details, students indicated that 'image processing' was the most popular area of study. Other popular areas included 'project management' and 'control systems', as shown from the data in Figure 6.

Furthermore, 67% of students believed that this module was a "valuable component in the degree programme". In fact, 37% strongly agreed that this was the case. Again, this reinforces previous findings in the literature that undergraduate students are generally in favor of active

TABLE 2 Survey questions used to evaluate the effectiveness of our hybrid teaching approach that aimed to develop 'systems engineers'.

Question	Description
Q1	Do you feel that the level of difficulty was appropriate for third-year undergraduate study?
Q2	Do you feel that this module helped you understand how to deal with complex engineering problems?
Q3	Was enough lecture material to guide the learning process?
Q4	Do you believe that this module helped improve your analytical and problem solving skills?
Q5	Do you feel that this module helped broaden your perspective in the area of electronic system design?
Q6	Do you believe that this module broadened your interest in other areas of study? If so, please indicate what areas?
Q7	Do you feel that this module was a valuable component in the degree programme?
Q8	Do you feel that the learning experience from this module will benefit your final year project?
Q9	Do you believe that this module will be useful for your future employment?
Q10	Would you recommend this module to your colleagues?
Q11	Do you believe that the range of assessment mechanisms were appropriate for this module?
Q12	Do you believe that the peer assessment should also be included as part of the assessment mechanism in this module? (Peer assessment involves students taking responsibility for assessing the work and performance of their peers against set assessment criteria.)
Q13	Do you believe that the assessments were similar to real world or authentic engineering deliverables?
Q14	Do you believe that working in a team helped you solve the design project given in this module?
Q15	Do you believe that working in a team helped improve your problem-solving skills?
Q16	Do you believe that working in a team helped broaden your perspective in electronic system design?
Q17	Has the module developed your awareness of team roles and your ability to work as a member of an engineering team?
Q18	Analyze technical requirements to develop an overall design plan.
Q19	Design, construct and test electronic hardware to perform specific functions.
Q20	Use a project planning methodology (such as Gantt charts) to define milestones and measure achievement against such milestones.
Q21	Run a project without undue reliance on the module instructor to perform productively as a team and to recognize contributions from all team members.
Q22	Write a concise researched technical report that clearly addresses and analyses a particular issue or challenge.

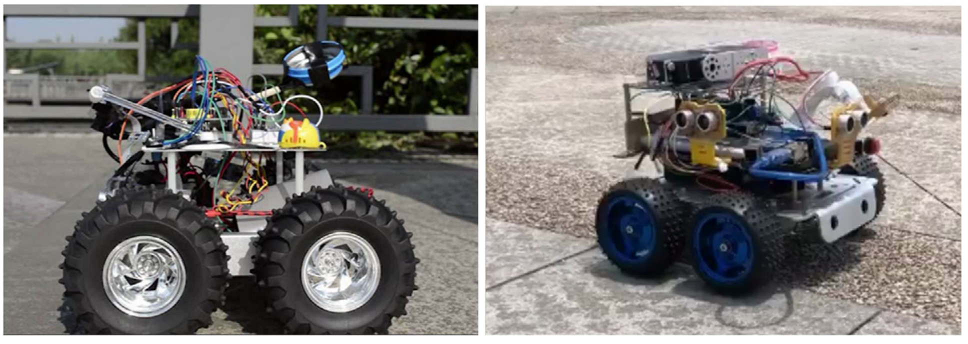

FIGURE 4 Sample images of the rovers developed by the teams of students. These rovers were designed to detect images, lines, transmit information and carry an item.

learning techniques.[48–51] Most importantly, 90% of students believed that this module was useful for their future employment (Q9), with almost one third strongly agreeing that it will help them in the future. Similarly, 68% of students either agreed or strongly agreed that they would recommend this module to future students (Q10). Only 3% of students strongly disagreed, or disagreed that they would recommend this module to future cohorts.

5.3 | Section 4 results - student teamwork experience

Despite 82% of students agreeing that the range of assessments was appropriate for this module, there were still areas for further improvement. For example, as evidenced from Figure 7, peer assessment mechanisms could have been introduced during module delivery.

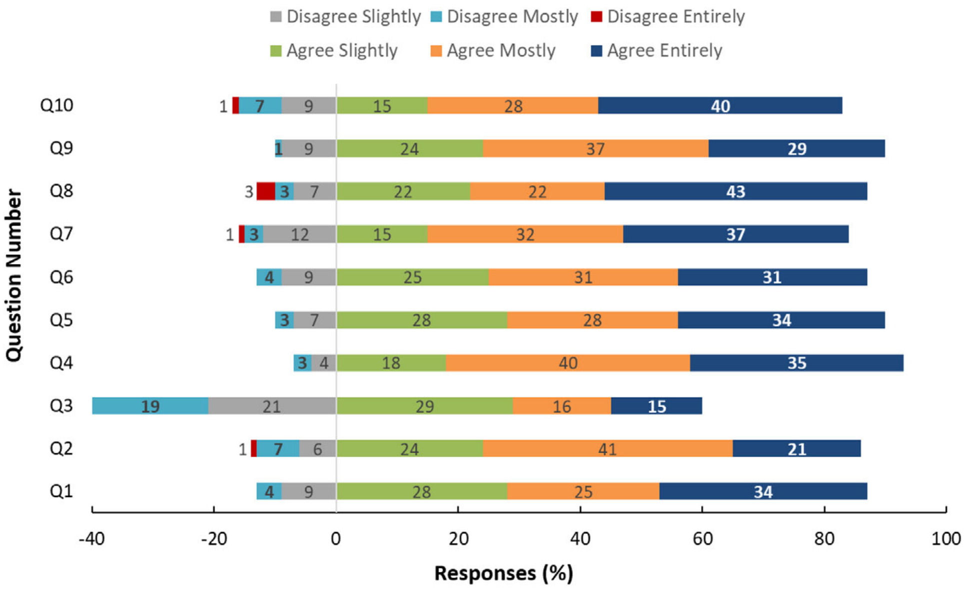

FIGURE 5 Student responses to Section 2 survey questions. The first 10 questions were: Q1: Do you feel that the level of difficulty was appropriate for third-year undergraduate study? Q2: Do you feel that this module helped you understand how to deal with complex engineering problems? Q3: Was enough lecture material to guide the learning process? Q4: Do you believe that this module helped improve your analytical and problem solving skills? Q5: Do you feel that this module helped broaden your perspective in the area of electronic system design? Q6: Do you feel that this module broadened your interest in other areas of study? If so, please indicate which areas? Q7: Do you feel that this module was a valuable component in the degree programme? Q8: Do you feel that the learning experience from this module will benefit your final year project? Q9: Do you believe that this module will be useful for your future employment? Q10: Would you recommend this module to your colleagues?

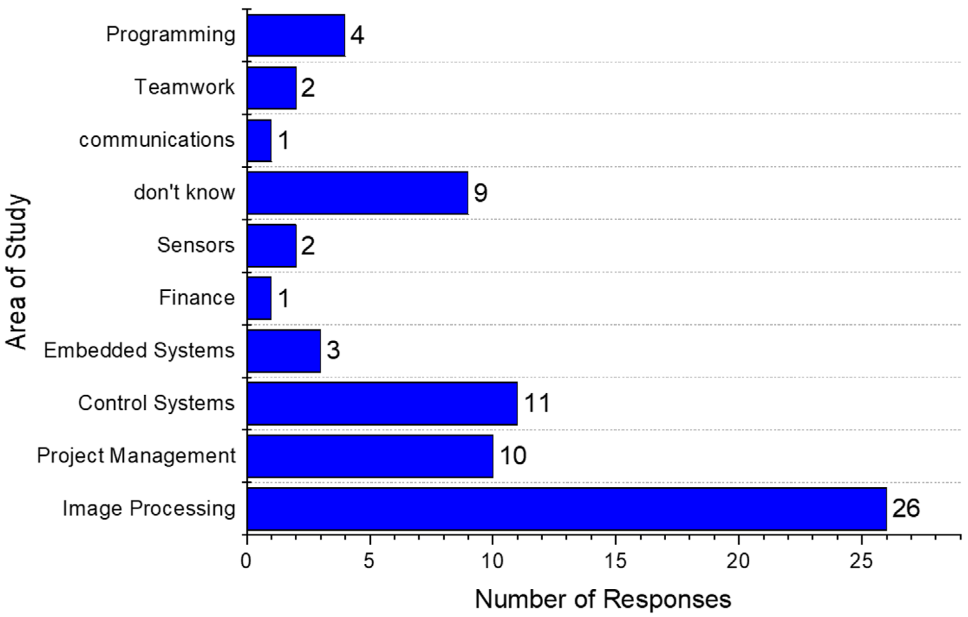

FIGURE 6 Areas of further study that have been learned during this module. Vast majority of students mentioned that Image Processing, Project Management and Control Systems were the most popular areas of further study.

According to Q12 student responses (cf. Figure 7b), 69% of respondents requested peer assessments to form part of the module's assessment diet. Similar sentiments are noted in the literature,[52,53] where students expressed a desire to critically evaluate the efforts of individual team members, which may lead to a more comprehensive evaluation of student work, especially free-riding students.

However, there are concerns regarding the effectiveness and reliability of student peer assessments, where grades may be in doubt or question.[52] Assessment is about making judgements concerning the certified level to which students achieved the criteria of the subject, which is why universities employ trained academics to make these judgements. Therefore, students may not have the necessary expertise

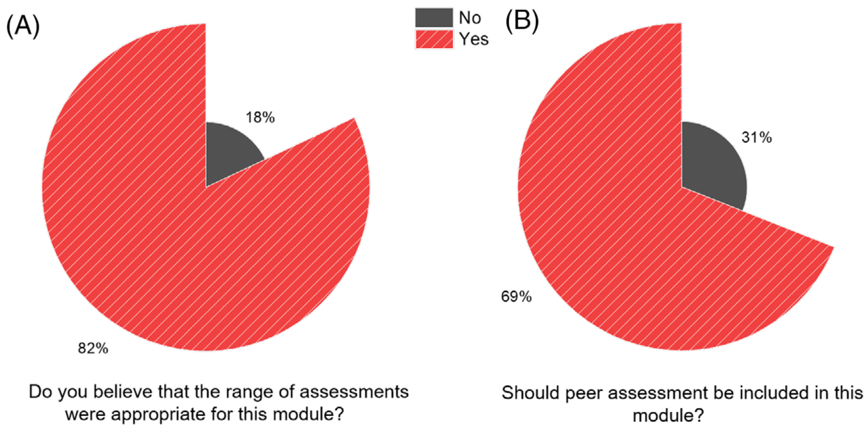

FIGURE 7 Students responses to (A) question 11 and (B) question 12 in the survey. The majority of students were clearly satisfied with the range of assessments, but felt that peer assessment should be included in the future.

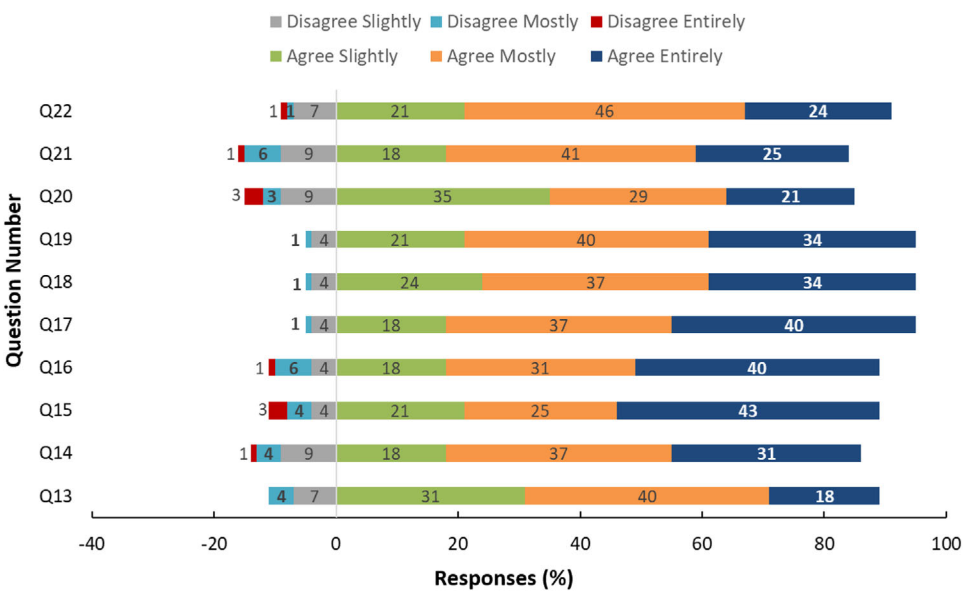

FIGURE 8 Student responses the survey questions. The questions were: Q13: Do you believe that the assessments were similar to real world or authentic engineering deliverables? Q14: Do you believe that working in a team helped you solve the design problem given in this module? Q15: Do you believe that working in a team helped improve your problem-solving skills? Q16: Do you believe that working in a team helped broaden your perspective in electronic system design? Q17: Has the module developed your awareness of team roles and your ability to work as a member of an engineering team? Q18: Has the module enabled you to analyze technical requirements to develop an overall design plan. Q19: Has the module enabled you to design, construct and test electronic hardware to perform specific functions. Q20: Has the module enabled you to use a project planning methodology (such as Gantt charts) to define milestones and measure achievement against such milestones. Q21: Run a project without undue reliance on the instructor to perform productively as a team. Q22: Write a concise researched technical report that clearly addresses and analyzes a particular issue or challenge.

or knowledge to accurately evaluate their peers' work. In fact, Rowntree cautions that peer assessment should only be used in a "summative assessment system whose outcome is not a grade or label but a profile of the student".[54] Therefore, further investigation is necessary before implementing any form of peer assessment, especially since students may rate their peers unfairly or inconsistently.

Moreover, 58% of students entirely or mostly agreed that that the range of assessments (oral presentation, demonstration, team report, lab report and individual report) were similar to real world or authentic engineering deliverables, as shown from the results in Figure 8 (Q13).

Another important aim of the module was the encouragement of teamwork and collaboration. The module aimed to provide opportunities for collaborative learning, and to share knowledge in ways that are similar to the real world. Therefore, in Section 4 of the questionnaire, students were asked a series of questions regarding teamwork and these results are shown in Figure 8. In fact, 86% of students agreed that the module enabled them to work in a team to solve the given design problem (Q14). Furthermore, 31% entirely agreed that working in a team helped students improve their problem solving skills (Q15). Most importantly, 43% of student entirely agreed that working in a team helped "broaden their perspective in electronic system design" (Q16). 77% of surveyed students agreed the module developed an understanding of team roles and for them to understand how to work effectively in a team (Q17). Indeed, the main reason for students to collaborate is that the task was complex and too difficult to complete alone. Therefore, our course was designed such that rover design and development required teamwork and collaboration. In fact, the rover had too many constituent parts and was complex enough for it to be completed alone. As previously mentioned in the literature, such complex activities require "positive interdependence", a situation in which completing the task and getting a good grade required the team to work together and share knowledge.[55]

5.4 | Section 5 results - module's ILOs

Finally, in Section 5 of the questionnaire, it was important to understand how well the ILOs have been met. Students were asked whether they were now able to analyze technical requirements and to design, construct and test electronic hardware to perform specific functions. 95% agreed that these ILOs have been met (Q18 and Q19). Other ILOs that perhaps needed further attention involve using project planning methodology to define milestones and measure achievement against such milestones (Q20). Students perhaps need further training in this area, especially from disciplines that involve operations research to become better familiar in project planning. Only a small minority (15%) felt that this ILO has not been completely fulfilled. A similar minority (17%) also felt that they were unable to "run a project without undue reliance on the instructor to perform productively as a team". These low numbers indicate that the vast majority of students are perfectly capable of running and executing their own projects, without instructor support or intervention. In fact, only a small number of students (1%) strongly felt the need for close supervision. These results ought to assure future course developers that even in such large classroom sizes (320 in this case), instructors only need to focus their attention on a small number of students that genuinely need help. Moreover, by encouraging all students to keep well-maintained ELNs, instructors can quickly identify which teams need support and when. Finally, 91% of students felt they were capable of writing "a concise researched technical report that clearly addresses and analyzes a particular issue or challenge", as shown from the results in Figure 8.

5.5 | Instructor feedback and student performance

Instructor feedback has been positive, with Instructor A mentioning: "The students really enjoyed this learning approach, they found it to be a great way to develop their skills and work together on a problem. It was also very successful in helping them to understand the concepts that are being taught in the course". Feedback from Instructor B was similar, saying "The team based approach has really encouraged students to engage, and they seem to be really enjoying the subjects they are studying. It's an effective way of teaching a subject and making sure everyone is getting the same amount of help and guidance, and that everyone is on the same page".

Next, student grades during the 5 years that the module was delivered are shown in Figure 9. While there is skepticism regarding how well grades reflect student attainment, they are often used to reflect how well students have grasped a module's ILOs.[56] It is argued that higher grades indicate higher attainment and understanding of these ILOs. Accordingly, average grades for the TDPS module were excellent and varied between 78% to 82% during the past 5 years, as shown in Figure 9. These average grades have been sustained, despite the increase in student enrollment numbers, which have almost trebled from 128 in year 1 to 320 in year 5. These student numbers are by far larger than those investigated by the literature.[15,20] Furthermore, student pass rates were 100% in years 3 and 4 as well as 99.1% in year 5, which means that very few students retook the module the following year, since dropping out was not an option. The standard deviation in student grades also fluctuated quite considerably. Notably, it dropped by almost a third to 2% from years 2 and 3, as shown from Figure 9. This could be attributed to better student collaboration on the group projects, leading to more uniform understanding of the material and being able to perform more similarly. The subtle rise in years 4 and 5 could be attributed to a small increase in the number of students with diverse academic backgrounds.

This narrow variability in student performance may indicate that all students are performing at a similar level, which could be a positive sign. However, it may also suggest that the design project is not challenging enough for the stronger students, who need to continue learning and growing. Therefore, an improvement may be achieved by introducing a new set of design tasks every third year of module delivery. In doing so, students who have taken the module before would not have an advantage over new students who have not seen the previous design tasks. This would help reduce the potential for students to simply reuse their previous work and instead encourage them to engage more deeply with the new design tasks. Additional research is also needed to explore how student grades are affected when instructors select student groups, rather than students choosing their own groups.

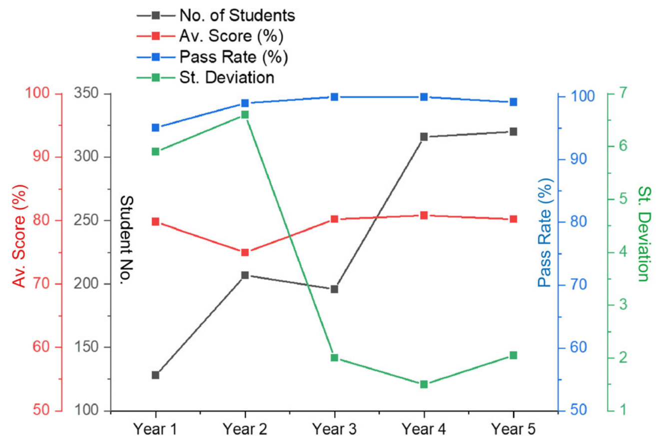

FIGURE 9 Student statistics for the TDPS module during the past 5 years. The graph shows average number of students, average scores, the pass-rate and the standard deviation in student grades. Further work is required to investigate the narrow standard deviation in student results. TDPS, Team Design and Project Skills.

6 | CONCLUSIONS

Transitioning students from classical structured problems through worked examples to ill-defined problems is a subject of interest in the literature. This article demonstrates how a hybrid learning approach that combines TBL and PBL has been used to design a new third year module called TDPS. The module was concerned with dividing 320 students into groups of eight in order to develop a rover that accomplishes a number of technical tasks. The motivation was to expose students to real-world authentic engineering problems and to develop graduate attributes that are required by the continuously shifting job market. All students were given a predefined budget and were required to complete their products within 17 weeks. The module was exclusively based on practical hands-on skills development and there was no exam component. Thus, the module has been well received during the past 5 years of instruction, with student numbers increasing from 128 to 320.

In fact, despite the challenges of block teaching in a transnational programme, where students do not manage to meet their supervisors on a regular basis, student attainment has been exceptionally high, even though student numbers have been increasing during the past 5 years. Therefore, these high student grades are a testament to the effectiveness of this teaching approach, despite the challenges of block teaching and growing student numbers in a transnational programme.

A carefully designed survey consisting of 22 questions was used to probe student satisfaction. According to our surveys, which were completed by 68 students, 83% admitted that the module was a valuable component in their degree programme. There were five assessment components, which involved presenting the project, demonstrating it, writing a technical report. Moreover, 82% of the surveyed student agreed that these assessment were appropriate for the module. However, there are areas for further improvement. For example, students indicated a preference towards an increased number of lecture hours. To achieve this, supplementary online and interactive learning activities will be developed for students, which will be shared on the module's dedicated VLE. Due to the positive impact our approach had on student experience and learning, as evidenced from the evaluative surveys, we aim to extend our investigations and develop more interdisciplinary projects according to student feedback. This is to ensure that our module is appealing to a wide range of students from different engineering disciplines.

Therefore, the success of this module provides an example of how TBL and PBL can be effectively combined to create an innovative and engaging learning experience for students.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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