Interdisciplinary Project-Based Learning: Experiences and Reflections from Teaching Electronic Engineering in China

Hua Fan, *Member, IEEE,* Huajiang Xie, Quanyuan Feng, *Senior Member, IEEE*, Edoardo Bonizzoni, *Senior Member, IEEE*, Hadi Heidari, *Senior Member, IEEE*, Michael P. McEwan and Rami Ghannam, *Senior Member, IEEE*

***Abstract*—Continuous developments in the electronics industry have led to constantly changing career roles and graduate skills requirements. Students in the University of Electronic Science and Technology of China (UESTC) have complained that numerous courses in electronic engineering are heavily focused on theoretical knowledge that is disconnected from the needs of industry. Thus, in an effort towards delivering student-centered educational programmes that meet the needs of industry, this paper introduces an innovative course that was developed using the project-based learning (PBL) method and situated in the electronic engineering undergraduate programme at UESTC. Since real-world engineering projects require teams to collaborate on ill-defined problems, we focused this innovative course on developing professional and technical skills, drawing from a range of more typical electronic engineering courses. We provide full details of two projects that were created for this PBL approach and evaluate them as practice examples that demonstrate the impact of this practical pedagogic innovation in UESTC. According to our evaluation, completed by all 40 of our enrolled students, our innovative course based on interdisciplinary PBL exercises demonstrated a significant improvement in student satisfaction and 65% of students preferred the interdisciplinary PBL course in comparison to traditional lecture-based courses.**

***Index Terms*—Course-related projects, Project Based Learning, Innovative training programme, Curriculum Design.**

I. INTRODUCTION

Manuscript received YYY, 2021; accepted XXX, 2021. Date of publication QQQ, 2021; date of current version ZZZ.

The work of Hua Fan was supported by Sichuan Provincial Science and Technology Important Projects under Grant 2022YFG0164, supported by the Open Foundation of the State Key Laboratory of Electronic Thin Films and Integrated Devices under Grant KFJJ202006, supported by the Fundamental Research Funds for the Central Universities under Grant ZYGX2021YGLH203, and supported by Intelligent Terminal Key Laboratory of Sichuan Province under Grant SCITLAB-1001.(Corresponding author: Hua Fan.)

Hua Fan and Huajiang Xie are with the State Key Laboratory of Electronic Thin Films and Integrated Devices, School of Electronic Science and Engineering, University of Electronic Science and Technology of China, Chengdu, China (e-mail: fanhua7531@uestc.edu.cn, huajiang163@126.com).

Quanyuan Feng is with the school of information science and technology, Southwest Jiaotong University, Chengdu, China (e-mail: fengquanyuan@163.com).

Edoardo Bonizzoni is with the Department of Electrical, Computer and Biomedical Engineering, University of Pavia, 27100 Pavia, Italy (e-mail: edoardo.bonizzoni@unipv.it).

Hadi Heidari,Michael P. Mcewan and Rami Ghannam are with the Electronics and Nanoscale Engineering Division, School of Engineering, University of Glasgow, G12 8QQ, Glasgow, UK (e-mail: hadi.heidari@glasgow.ac.uk, Michael.Mcewan@glasgow.ac.uk, rami.ghannam@glasgow.ac.uk).

Digital Object Identifier 10.1109/TE.2018.xxxxxxx

CONTINUOUS developments in the electronics industry warrant the need for innovative, digitally literate and independent engineers who are prepared for the real-world challenges that lie ahead [1]–[5]. Thus, creative undergraduate courses that rely on active learning methods are required to meet these needs. In many universities in China, it is common for large cohorts of students to be taught abstract lecture-based courses with little access to practical training. Traditional lecture-based courses that rely on the ‘banking’ approach primarily focus on ‘depositing knowledge in the minds of the learner’ [6], [7]. This teaching approach has been criticised 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. The literature also refers to such teaching methods as ‘teacher-focused’, inhibiting criticality, thus students are perceived as passive learners [8]–[10].

Therefore, based on China’s continuous encouragement for implementing non-traditional teaching methods in classes [11], this paper introduces several promising approaches to help students develop knowledge and skills that meet the needs of industry. Instead of students learning scattered facts, we demonstrate a teaching approach that has been successfully adopted in a university in China, which focuses on engaging students with the key threshold concepts [12], [13], i.e. concepts that are key to the mastery of a subject [14]. As mentioned by Baillie *et al.*, such threshold concepts are transformative and can be very difficult to acquire at first, and so engaging, active learning pedagogies are a robust way to facilitate learning these concepts.

In addition to acquiring these threshold concepts, students are encouraged to develop their communication and collaboration skills; graduate attributes which are increasingly required by the continuously shifting global job market. Accordingly, we aim to promote deeper, active and more practical learning by encouraging students to take part in carefully designed projects that were co-created alongside our industrial partners [15]–[17].

This paper presents two key examples of interdisciplinary project-based learning (PBL) exercises that have been co-created and can be integrated in any electronic engineering programme to facilitate deeper, active and more practical learning. Our aim is to demonstrate the benefits of developing learning activities that are interdisciplinary and student-centered. Through these activities we expected students to draw on lessons from several electronic engineering disciplines and apply them in a practical way. We also aimed to develop important professional skills such as problem-solving, decision-making, communications and collaboration skills.

Consequently, these interdisciplinary projects were designed to facilitate collaboration among students, so that they "construct" a shareable product [18]. In doing so, students gain their own technical and professional skills required to complete an electronic engineering project, instead of relying on the instructor to depart knowledge [12]. In the long term, students were expected to develop a habit of active learning and to think deeply about the interconnection between related knowledge. Such changes are highly beneficial for the cultivation of innovation and resourcefulness [19]–[21]. Since students are active learners and stakeholders in the learning process, instructors are expected to use student feedback to evaluate and refine the teaching and assessment materials, ensuring a strong staff-student partnership. Such feedback can help with the development of new teaching materials or methodologies influenced by the pedagogy of the subject. Therefore, this paper also presents an evaluation of these interdisciplinary PBL exercises by exploring the experiences of both the teachers and the Chinese students who are key stakeholders in this PBL approach. As previously reported in the literature, these active learning activities have previously demonstrated favourable student feedback in the context of transnational engineering programmes with Chinese counterparts [22], [23] and we aim to demonstrate the same in this in-country context.

Using these interdisciplinary PBL exercises, We aim to encourage students to think unconventionally during class, to practice creatively after class, and to link theory to practice [24]. Moreover, strengthening collaboration between universities and enterprises (top collaborative companies engaged with the university) is among the objectives of the development of the UESTC engineering programme. We aim to achieve this via these PBL projects, which were designed in partnership with industry. Such cooperation provides students with technical experience in real-world engineering problems [25].

The outline of this paper is as follows: Section II demonstrates and discusses the curriculum development in the UESTC engineering programme. Two related projects designed for the curricular reform are presented in section III. An evaluation of the PBL approach is outlined in section IV with its results presented in section V. Finally, conclusions and possible future paths are addressed in section VI.

II. Background

It is becoming more challenging for course teachers to cover the entire field of electronic engineering within a typical four-year undergraduate programme. Moreover, industries expect graduates to have acquired essential graduate attributes such as teamwork, problem solving and critical thinking within this short period. Universities are, therefore, under pressure to design innovative electrical engineering programs that meet these requirements and encourage more students to apply, despite declining student enrollment numbers.

Consequently, we have introduced active learning strategies that rely on the project-based learning (PBL) method into our curricula. PBL encourages students to learn by engaging themselves in real-world projects [26]. Project-based learning facilitates the interconnection between multiple courses and promotes students' deeper learning [27]. Some of the main characteristics of the PBL method and its comparison with problem-based learning and traditional lecturing are well documented in [27]. For example, high levels of student engagement, collaboration, team-work and constructivist learning are highly valued and supported in the PBL method.

Despite problem-based learning being an active learning method, it focuses on searching for required knowledge and finding effective solutions, whereas project-based learning relies on the flexible use and integration of knowledge around interlinked problems [28]–[30]. Moreover, PBL aims to encourage students to work together in teams so that they can better integrate interdisciplinary knowledge and to transfer that knowledge into practical skills [31], [32]. Thus, PBL meets the intentions of our curricular reform: to create a learning environment that facilitates communication, interlinked learning, teamwork, the development of graduate attributes and deeper, active learning.

A. *Current curriculum structure*

The University of Electronic Science and Technology of China (UESTC) was built in 1956. In 2001, it was one of 39 universities to receive special funding from the State's "Project 985" program and is currently ranked first in China in the field of electronics. In 2013, UESTC started to redesign its curricula. Significantly increased knowledge requirements are now integrated into every single subject in the new university curriculum, and this increases the requirements on courses to be interconnected and requirements on what students need to learn. Accordingly, students' deep understanding and interconnection between multiple courses and real-world professional skills are required more than ever before. To facilitate this, the individual elements of electronic engineering curricula should be interlinked and connected. For example, combining several highly relevant courses into a single connected course would be an effective solution. A typical example of a redesigned curriculum involves combining key learning outcomes from the "Circuit Analysis" and the "Fundamentals of Analog Circuits" courses into one integrated course called "Electronic Circuit Foundations". As part of this connected curriculum redesign UESTC has also introduced the latest software tools used by industry. For example, Multisim and Cadence software packages are now part of the curriculum. This approach helps students cultivate the necessary digital skills required by industry. Introducing these software packages in courses has drawn positive feedback and recognition from peers [33], but also ensures that the curriculum is strongly connected to industry and is authentic.

B. *Emphasis on practical experiences*

Students in UESTC have often requested a greater emphasis on practical learning experiences and project-based learning can be an effective solution. Projects involve synthesising and applying knowledge from multiple subjects and courses, and so can help connect curricula. With that being mentioned, projects of different themes and different levels are offered to students in UESTC. Teamwork on the projects is highly encouraged to facilitate a socially constructive learning environment. In this learning environment, students are often required to think and learn more independently that in more traditional classrooms. For example, a more critical pedagogy may involve creating open debates that require students to develop arguments, study independently and present their own conclusions (e.g. whether DC or AC power generation should be adopted, or debate the importance of analog versus digital circuits in the electronics field). These approaches showcase a more critical pedagogy. Such a critical pedagogy is more effective when compared with the traditional, passive ‘banking’ approach: it is more active, engaging and student-centred [7], [10].

In setting up project teams students are either divided randomly into 3-person teams or they select their own teammates. When communicating with students about grouping during the teaching work, we learned that students need to find out each teammate’s strengths and learn how to best collaborate in a random division, which enhances their collaboration skills. In the cases where students create their own teams, students usually select members who possess complementary skills, for example one for hardware, one for software, and one for writing. This makes it efficient for students to distribute the project requirements and learn with and from each other. Recognizing a need to recruit and retain students, especially in China where birth rates have declined and there is a lack of collaborative projects and student-centered education, this project-based approach focuses on developing key threshold concepts in engineering to try to transform the way students view and understand the subjects [34] and increase numbers in this critical STEM field, as well as developing communication and collaboration skills in teamwork that are required by the global job market and important to higher education [35]. As one of the key teaching methods, these projects are specially designed such that knowledge of multiple subjects is combined in one project, and students have to develop a thorough understanding of the connections between these related subjects.

III. Methodology for Project Design

Fig.1 shows how the learning outcomes from different courses were effectively integrated into a particular project. For example, students need to review what they have learnt from the “Sensor-Based Systems” course to select appropriate sensors for detecting certain physical signals. Subsequently, students need to design amplifiers and filters, which requires knowledge from the “Design of Analog CMOS Integrated Circuit” course. To realize the control of different modules, students need to synthesize knowledge from the “Embedded Systems Design” course. Moreover, knowledge of dealing with outputs is imperative for getting final results and drawing conclusions. The printed circuit board (PCB) design and layout skills can be drawn from the “Electronic Systems Design” course. By using a project based approach like this, learning outcomes from multiple courses can be integrated so that students are encouraged (and required) to have a more comprehensive, deeper knowledge basis to successfully complete their projects.

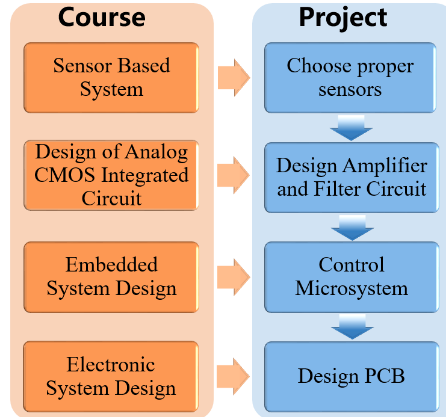

Fig. 1. Projects were designed so that they are strongly linked to existing courses in the teaching programme.

Strengthening collaboration between universities and enterprises is also a significant method of this PBL-reform. Therefore, we made full use of the diverse range of resources available from both the university and the enterprises. The teaching team consisted of experts from top enterprises and award winning teachers from the university. Moreover, the latest research applications and practical research projects from industry were introduced into our course. These enterprises also provided students with internship positions, which guaranteed that students obtained gainful employment. Moreover, corporate experts regularly visited the school and delivered guest lectures to our students [36]. At the same time, UESTC introduced an electronic virtual laboratory as a teaching simulation platform to supplement the practical laboratories. Senior professor, Franco Maloberti, from the University of Pavia (Italy) was therefore invited to deliver lectures on this topic, since he is an advocate of using software to enhance learning via the simulation of real hardware functions. Therefore, through these practical projects, students were equipped with skills and experiences that would prepare them for leadership careers in industry and academia.

Such cooperation greatly improves students’ real-world professional skills and significantly promotes the development of innovative training. In recent years, UESTC developed collaborations with 13 enterprises, where 117 students completed internships. During the past two years, the school kept close contact with 36 enterprises and research institutions to provide students with real-world professional skills. We involved our industrial partners in the PBL project creation in multiple ways. As previously mentioned, industrial experts were invited to teach certain courses. They guided students through entire projects and shared authentic experiences in dealing with potential problems in real-world projects. Moreover, some students were sent to enterprises to take part in an authentic

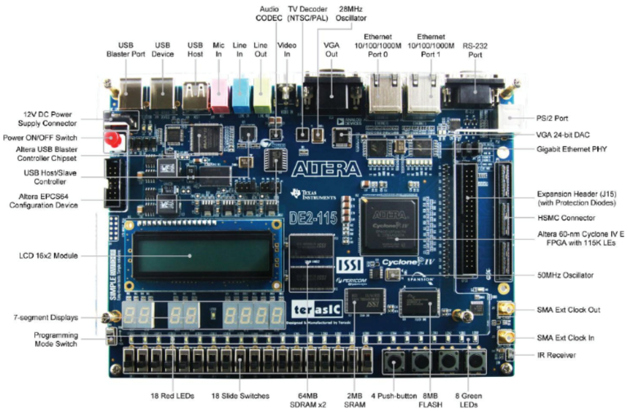

Fig. 2. Altera's DE2-115 FPGA board for teaching and research, the DE2 series FPGA development boards have long been acclaimed for their rich and diverse peripheral interfaces, and have been the leading educational development platform and the first choice of laboratories in 1000 schools worldwide.

project. Such cooperation greatly promotes the development of innovative training and continues to promote mutual benefit and cooperation between UESTC and the enterprises.

A. An Example Project: Image Edge Detection

One of our projects involved an image processing task. In this project, students compared the performance of single and multi-core processors for various image processing problems on the FPGA board in Fig.2. During this process, students explored the architecture of embedded systems and how the Application Binary Interface (ABI) can be used to embed assembly functions in C programming language. Moreover, students were introduced to 'interrupts' and how C-Macros can be used to access the system library of embedded peripherals. Therefore, this project expected students to develop a sound understanding of how software can be used to programme an important electronic (hardware) platform.

Therefore, this project involved both hardware and software image processing activities. Students need to print out images using ascii symbols. The final goal is to process 320, 32×32-pixel pictures per second, to ensure that the size of the programme is within 45 kB. This needs to be achieved given the following conditions:

- The clock frequency is 50 MHz.
- The is no floating-point unit.
- A total of five CPUs can be used, of which four CPUs have their own independent 8 kB memory. Each CPU has an 8 kB independent memory and an 8 kB shared memory.

The overall project was divided into two parts. During the first part, students needed to work in teams to develop the process steps shown in Fig.3. Next, they needed to convert the functions described in each of these steps into the appropriate C programming language. Subsequently, students needed to consider different ways for optimising their processing times, which required experimentation with single and multi-core programmes. Here, instead of relying on a single core, students were expected to appreciate that multiple CPUs can be used to improve these processing times. In fact, there were many ways for achieving multi-core programming. Therefore, students needed to critically engage with the task. They also needed to reflect, evaluate and make decisions themselves, so that the most effective method of operation was chosen. Ultimately, students were expected to achieve the image processing results shown in Fig.4.

B. A Second Example Project: Physical Activity Monitor

In a second project, which aimed to train students in appreciating the importance of sensors and what they can achieve, students were tasked with designing a physical activity monitor. This required the integration of different types of sensors.

The activity monitor was designed to help people understand how heavy they can lift certain objects and how to safely lift these objects without injuring themselves. This is particularly useful for weight trainers, so that they can effectively lift weights according to their personal body conditions. Such devices can reduce the risk of injury and enhance athletic performance. By developing this physical activity monitor, students learned how to combine wireless communications technology, automation technology and Android technology together.

As shown in Fig.6, this project consisted of a wearable physical activity monitor, which measures the user's body angle and elbow bending angle. Based on this data, the device was able to detect body position and the physical activity of users.

In this project, a STM32F3 discovery board, an accelerometer, and four light-based flex sensors were used. The STM32 discovery board works as a microcontroller and collects data from other modules. The STM32F3DISCOVERY allows students to easily develop applications with the STM32F3 Series based on ARM Cortex-M4mixed-signal MCU. In addition, an accelerometer, gyroscope and e-compass ST MEMS, USB connection, LEDs and push-buttons are included in STM32 discovery board. The accelerometer can detect the body angle with a precision of 1 degree, a sufficient resolution for this project. Flex sensors were used to detect the bending angle of elbows, students were encouraged to make sensors by themselves in order to achieve a better understanding about the fundamentals of sensors.

Velostat material based flex sensors were considered too unreliable for this project due to comfortability and reliability requirements. Thus, light-based flex sensors were adopted. Light-based flex sensors work on the principle that the resistance of light-dependent resistor (LDR) increases with decreasing incident light intensity. This type of flex sensor detects different light intensity when sensors are bent resulting in changes in output voltage in the circuit. In comparison to the Velostat sensors, which depend on the physical location of the sensor on the body (something that can not be easily controlled), this type of sensor is considered more reliable, since the output depends on the bending angle [37]. In this project, students are encouraged to design and make sensors by themselves so that they can explore the Velostat and light-

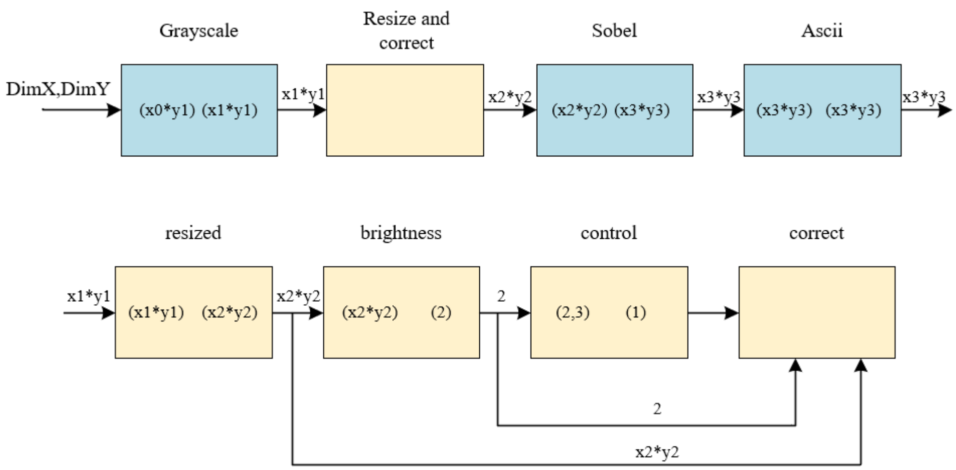

Fig. 3. Image processing task workflow. The blue box represents the processing task, while the yellow box represents the optimization task. The corresponding amount of data will be transferred to the next box upon task completion.

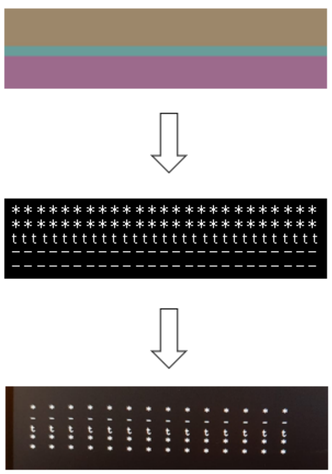

Fig. 4. Image processing result, from the input image to the theoretical output result to the actual output result, the edges of different colors are recognized and converted to ascii code.

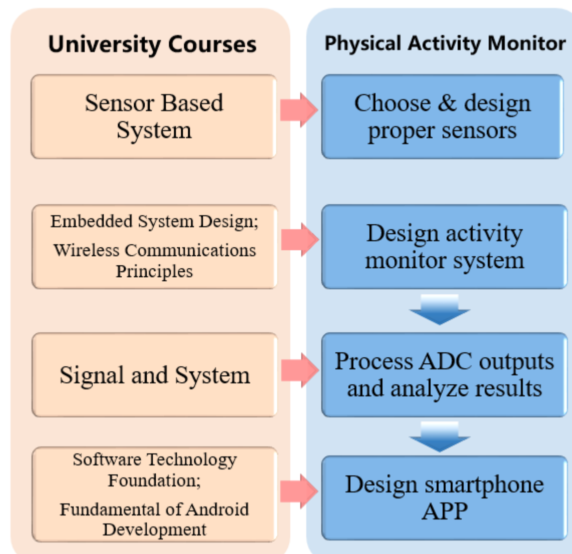

Fig. 5. University courses involved in physical activity monitor project.

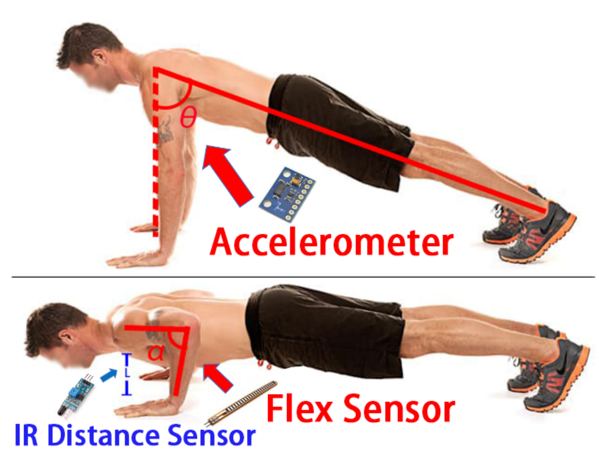

Fig. 6. Body position measured by different sensors.

based sensors for reliability, which helps them discover practical limitations of their design choices. Through this process of testing different sensors, students will compare different design approaches so that they can appreciate how sensors work and what their limitations are in terms of sensitivity, resolution and deviation, etc.

During their testing of the flex sensors, each sensor was bent in four system configurations (0-25 % bent, 25-50 % bent, 50-75 % bent, 75-100 % bent). In order to get an accurate result, samples should be measured as much as possible. In this project, one thousand measurements of the analog-to-digital converter (ADC) output were made for each of these configurations. By analysing the data and results, students are encouraged to make their own decisions regarding the most optimum method for using these sensors. For example, students can learn from this data the best types of exercises (push-ups, chair, plank, weight lifting, etc.) that can be further

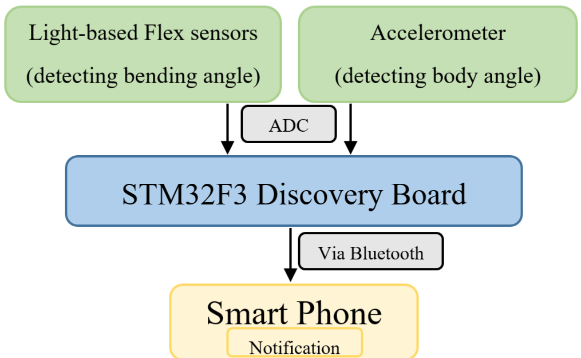

Fig. 7. Physical activity monitor architecture, the sensor transmits data to the STM32 via ADC and finally to the smartphone via Bluetooth.

included an accompanying APP (to be developed by students as part of the project), so that the system can identify them and advise its user how best to perform these exercises.

After all the necessary modules were installed and tested, an Android APP should be developed for better convenience of using this physical activity monitor. It enabled the user to connect the device via the bluetooth module. When the user is connected, the APP will read data that has been transmitted from the MCU. The data was then communicated to the user via a screen. A real-time operating system (RTOS) was also used in the project, so several instructions can be processed in different time intervals. This step helped students become familiar with system architecture. The sensors were sampled once every 1 ms and the average value from all the samplings was sent to the APP every 2 seconds. It was presented as the angle for each sensor and for each axis in the accelerometer. In addition, it will take the values and decide if the values are in a specific range. Depending on the results, the APP sends feedback to the user via a voice module. The structure of the entire system is shown in Fig.7.

Upon completion of the project, students were required to discuss the challenges encountered during the design process and come up with recommendations for this physical activity monitor in the future. Fig.5 shows how learning from several university courses in electronic engineering has been considered to complete this physical activity monitor project.

IV. Evaluation Methodology

In order to evaluate the PBL approach a stratified mixed methods survey design was adopted. Students were recruited from the 2017 and 2018 cohorts and asked to complete a standard (and frequently used) course evaluation survey after they completed their course. This sample comprised second year undergraduate students majoring in electronic engineering. The students from the 2017 cohort studied a more traditional 'lecture-based' curriculum, prior to the implementation of the PBL approach. Students from the 2018 cohort completed the transformed course involving PBL projects and thus were the 'intervention' group. Parallel to this, the class teacher on the programme also completed the reflective 'Approaches to Teaching Inventory' [38] in each setting (prior to and post implementation of PBL). By adopting this mixed methods approach the impact of the new teaching model on student evaluations can be determined and the developing understanding of the teacher's approach can also be illustrated.

Across both 2017 and 2018 cohorts, a total of 40 students were randomly selected to complete the course evaluations (100 % response rate). All 40 students were from the electrical engineering discipline and they participated in the course evaluations voluntarily. 20 students from both the 2017 and 2018 cohorts were randomly selected to participate in these evaluations to increase the generalisability of our results and to minimise bias. The survey was issued online immediately after the students completed their projects. Students participated via a consent form and all responses were anonymous. The teachers involved in delivering this course were the same for both semesters. Moreover, the topics and key requirements for each project were determined by 1 professor and 3 assistant teachers. Within the same course, several projects could be taken together, but only one teacher responsible for the course participated in the survey questions of the teaching methods inventory. The course evaluation questionnaire consisted of 8 questions. Students responded using a 5-point Likert scale, where "strongly agree", "agree" were considered to represent a positive attitude, whereas "disagree", "strongly disagree" were considered to represent a negative attitude.

The 'Approaches to Teaching Inventory' (ATI) [38], [39], completed by the class teacher, is a widely used and validated research instrument but it is also used to promote reflective practice amongst (particularly new) teachers in higher education. It consists of several 5-point Likert scale questions concerning the teacher's approach to and views on their teaching and helps teachers identify whether their approach is more teacher-focused or more student-focused. As teachers become more student-focused in their approach they are more likely to gradually transfer the focus of their educational approach towards increased student autonomy in the learning process [40]. The ATI comprises 20 questions, 10 of which score a teacher on their 'teacher-focused' approach and 10 of which score the teacher on their 'student-focused' approach. A teacher's completion of the ATI results in two scores that encourage the teacher to reflect on the extent of their teacher or student-centredness. A sample of the ATI questions asked in this survey is shown in TABLE 1.

V. Results and Analysis

Fig.8 shows the feedback collected from students' traditional lecture-based teaching approach used in 2017 and the new project-based teaching approach adopted in 2018. The redesigned PBL-based curriculum has so far received positive response. Responses collected from Q2, Q4, Q5, Q6, and Q7 together provide a positive outlook for the revised teaching approach. According to responses from Q2 "The instructor engaged the class in productive discussions" and Q6 "I had a great team working experience in the course" this indicates that students taking part in the new PBL course believe that they were more engaged in the class and there was a better environment for sharing knowledge. Sharing of knowledge is an important element of active and collaborative learning.

	Example Questions	Rarely				Always
Q1	It is important that this subject should be completely described in terms of specific objectives that relate to formal assessment items.	1	2	3	**4**	5
Q2	In this subject I concentrate on covering the information that might be available from key texts and readings.	1	2	3	**4**	5
Q3	Teaching in this subject should include helping students find their own learning resources.	1	2	**3**	4	5
Q4	In this subject students should focus their study on what I provide them.	1	2	3	4	**5**
Q5	I encourage students to restructure their existing knowledge in terms of the new way of thinking about the subject that they will develop.	1	**2**	3	4	5
Q6	In my interactions with students I try to develop a conversation with them about the topics we are studying.	1	2	**3**	4	5

Teacher-centered: Q1, Q2, Q4; Total points: 4+4+5=13
Student-centered: Q3, Q5, Q6; Total points: 3+2+3=8

TABLE I
EXAMPLE QUESTIONS OF APPROACHES TO TEACHING INVENTORY (ATI) FOR THE TEACHER [38]

.

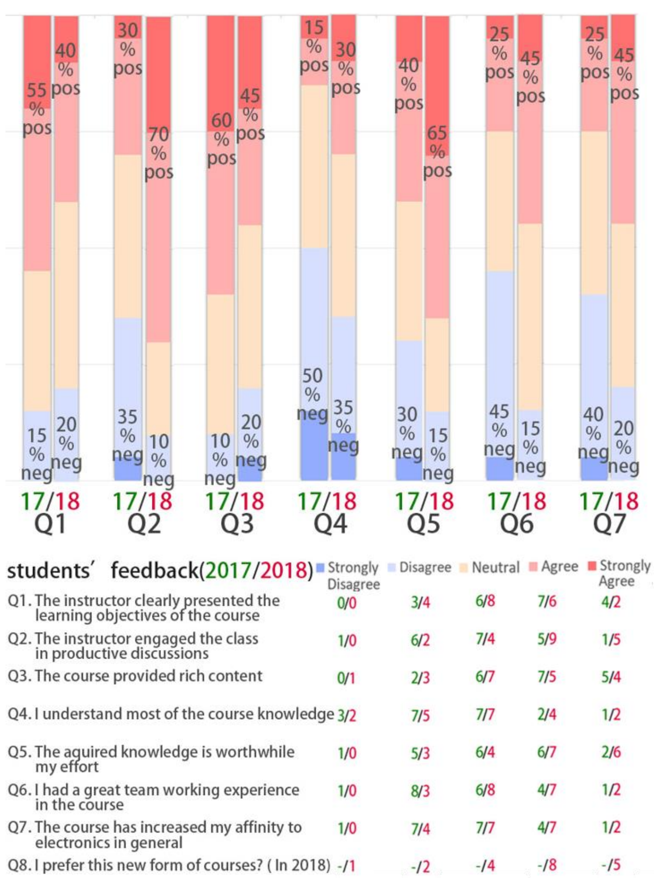

Fig. 8. Comparison between students' feedback on traditional lecture-based course and redesigned project-based course.

Similarly, results from Q5 show that 65 % of students believe the PBL course has benefited them in an effective way, in comparison to only 40 % in 2017. This new form of teaching clearly helped students gain a deeper understanding of the knowledge involved in the project, as well as their ability to apply theory to practice. Moreover, students gradually find the interconnections between relevant subjects, as the projects usually require multi-disciplinary knowledge. According to the course evaluation surveys and from the responses to question Q8 " I prefer this new form of courses", 15 % of the students prefer traditional lecture-based courses. 20 % of the students hold a neutral attitude. Whereas 65 % of the students prefer project-based courses over the previous lecture-based courses, which shows a trend of improvement in raising students interests. To gain further insight into the quality of our teaching methods, and to evaluate the effectiveness of our teaching techniques, we arranged interviews with several students. One of the interviewed students reported, "unlike the old teaching style, which I usually have no idea about what I can do after the class, now I'm clear about where I can use the knowledge from this course". This demonstrates that a major aim of the PBL approach has been achieved: that students can apply and transfer their knowledge to the authentic, real-world setting. The process of solving a real-world problem seems to be more appealing for the majority of students, but a small proportion still prefer lecture-based courses. This small proportion is to be expected as it is not uncommon for students to value more passive learning approaches, despite more active approaches resulting in better learning [41]. Students can feel that lectures present the learning objectives more clearly and can cover more content, whereas PBL-based courses require more initiative from students and greater self learning but result in deeper learning.

The red areas in Fig.8 are considered to be positive feedback for the course and the blue areas in Fig. 8 represent negative feedback. It can be derived that there has been an obvious improvement on the degrees of satisfaction with the redesigned project-based course in general. However, student feedback also demonstrated some apparent advantages for traditional lecture-based teaching approaches, which will be considered to better improve the new teaching approach in the future. According to student responses for Q1 "The instructor clearly presented the learning objectives of the course" and Q3 "The course provided rich content", our previous course in 2017 received 15 % more positive feedback in comparison to the new PBL course. On face value, this result indicates that students preferred teachers to convey teaching materials in a traditional lecture-based class. Similarly, less content was delivered by the teacher in our new course, which meant that students had to do more self-learning, which is among the aims of our new PBL course. When combining these two responses with the responses to other questions it is clear that the PBL approach pushes students beyond their traditional learning boundaries and encourages (perhaps unexpected) independence. By taking these responses into consideration, some modifications will be applied in the teaching approaches to provide students with more theoretical knowledge and support for independent learning before starting the projects.

In contrast to student evaluations, the PBL-based course is also evaluated from the perspective of teachers. The teacher in charge of the course completed the Approaches to Teaching Inventory. Fig.9 shows the comparison of questionnaire results for teacher before and after the curricular redesign. The figure illustrates the teacher-focused nature of the course in 2017. In comparison, since adopting more PBL approaches, the course teacher evaluated their approach as more student-focused. When reflecting on their 2017 teaching, the class teacher for this course completed the ATI which resulted in a teacher-focused score of 41 (out of 50) compared to a student-focused score of 24 (out of 50). This suggests a strong teacher focused approach in the traditionally designed 2017 version of the course. However, when completing the ATI based on the redesigned 2018 PBL course, the teacher focused ATI questions totalled only 32 compared to 36 for the student focused questions. This suggests a clear transformation that the course (and the practice of the teacher) has shifted towards a more student focused one in 2018. This transformation to a student-focused approach demonstrates that the PBL-based curriculum encourages more independence, more self-directed learning as well as placing more freedom for students on choosing their learning subjects; all factors related to fostering a deeper approach to learning, but also requires a corresponding shift in approach of the teachers.

Such a shift in teachers' approach needs support and training. Becoming a teacher in higher education takes time and involves professional development through both reflective practice and formal training. There are several stages of teacher development and this is a gradual process, from the inwards looking teacher-focused practitioner to the student-focused practitioner who is more comfortable allowing students to take a lead in learning [42], [43]. In the UK this teacher training is well established through the UK Professional Standards Framework for teaching and supporting learning [44] which enables teachers to work towards qualification and professional recognition through experiential and formal learning and development. This requirement for professional development has grown since it was first proposed by Dearing (1997) and then laterly formalised by the government [45]. Consequently, higher education teachers in the UK now typically complete postgraduate teacher training enabling discussion and experimentation with more innovative teaching pedagogies. If a significant shift in teaching approaches is to be achieved in China then a similar drive for professional development, either independently or through collaboration with UK partners (as is partly the case here) would support teachers and enhance these authentic educational goals.

It is important to note, however, that there are limitations to this study. The first is concerned with the small number of students (20) and teachers (1) who participated in this investigation. The second is related to the disciplinary background of the students. Here, our investigations were focused on electronic engineering students and did not consider students from other disciplines such as mechanical, telecommunications, information or computer engineering. The teacher was involved in educational development and thus perhaps demonstrated a biased, open mindset to development, and so a larger scale study in the future would be greatly beneficial to inform more significant policy change. However, our intention in this article was to show proof of concept. To showcase that our project-based learning approach has worked in this context, and that it can be successfully used by other academics wishing to move their teaching away from traditional lectures in a Chinese

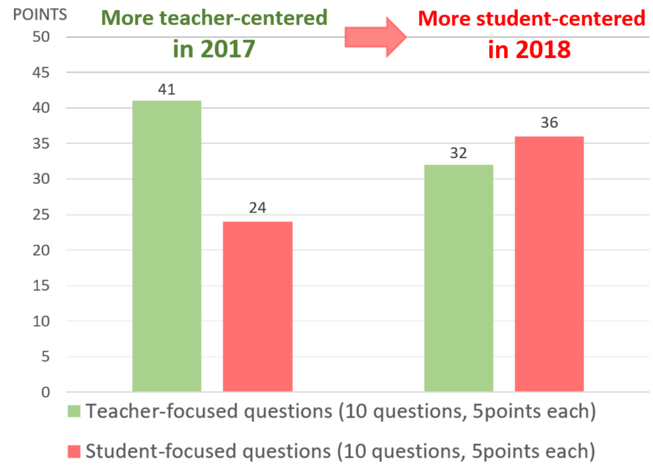

Fig. 9. Results of teaching evaluation questionnaires about 2017 more teacher-centered versus 2018 more student-centered.

higher education institute. We have also added evaluative data from students to showcase the positive impact this approach had on experience and learning. With that said, our goal is achieved and we invite the wider community to experiment with innovative pedagogies in more traditionally designed curricula.

VI. Conclusion

In this paper, we have highlighted the concerns of Chinese students regarding lecture based teaching, and our approach to replacing these with multidisciplinary project based learning (PBL) opportunities. In the past, students have complained that their courses were disconnected from industry needs. Our PBL-based teaching approach now places greater emphasis on testing students' ability to implement theoretical knowledge into practice, developing graduate attributes, and taking part in more active, deeper learning. Since practical experiences play an important role in electronics engineering disciplines, our aim was to engage students in projects that were co-created with industrial partners so that students can build a better connection between theory and real-world practice. We have successfully designed projects that combined the learning outcomes from multiple courses. Student feedback from our surveys showed that 65% of our students strongly preferred the new multidisciplinary PBL courses. Only 15% of students preferred learning through traditional lecture-based courses. Moreover, feedback from our surveys showed that there is a clear shift from teacher-focused to student-focused teaching. Students can therefore take responsibility for their own learning. For future work, we plan to modify the course-related projects according to student feedback. We expect to design more customized projects for students with different academic abilities and from diverse engineering disciplines. Despite the positive responses received from our students, we would like to extend our approach to more interdisciplinary courses and students from different backgrounds, since the surveys were only completed by one cohort that had 40 students enrolled. Nevertheless, evaluative student data clearly supports the positive impact our approach had on student experience and learning.

REFERENCES

[1] D. Q. Nguyen, "The essential skills and attributes of an engineer: A comparative study of academics, industry personnel and engineering students," *Global J. of Engng. Educ*, vol. 2, no. 1, pp. 65–75, 1998.

[2] D. Jonassen, J. Strobel, and C. B. Lee, "Everyday problem solving in engineering: Lessons for engineering educators," *Journal of engineering education*, vol. 95, no. 2, pp. 139–151, 2006.

[3] M. G. Violante and E. Vezzetti, "Guidelines to design engineering education in the twenty-first century for supporting innovative product development," *European Journal of Engineering Education*, vol. 42, no. 6, pp. 1344–1364, 2017.

[4] Y. Kim, T. Soyata, and R. F. Behnagh, "Towards emotionally aware ai smart classroom: Current issues and directions for engineering and education," *IEEE Access*, vol. 6, pp. 5308–5331, 2018.

[5] M. Prince, "Does active learning work? a review of the research. journal of engineering education," *Journal of Engineering Education*, vol. 93, pp. 223–231, 2004.

[6] P. Freire, "Pedagogy of the oppressed (revised)," *New York: Continuum*, 1996.

[7] E. F. Provenzo, "Critical issues in education: An anthology of readings," 2006.

[8] R. Nola and G. Irzik, *Philosophy, science, education and culture*. Springer Science & Business Media, 2006, vol. 28.

[9] R. Ghannam, H. Qammer, and S. Hussain, "Improving student engagement in a transnational engineering education programme using piazza," *Excellence in Engineering Education for the 21st Century: The Role of Engineering Education Research*, p. 33, 2019.

[10] M. Alam, "Banking model of education in teacher-centered class: A critical assessment," *Research on Humanities and Social Sciences*, vol. 3, no. 15, pp. 27–31, 2013.

[11] R. Hayhoe and J. Pan, *East-West dialogue in knowledge and higher education*. Routledge, 2016.

[12] F. Marton and R. Saljo, "Approaches to learning," *In F. Marton, D. Hounsell, & N. Entwistle (Eds.), The experience of learning*, pp. 36–55, 1984.

[13] J. Meyer and R. Land, *Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practising within the disciplines*. University of Edinburgh, 2003.

[14] G. Cousin, "An introduction to threshold concepts," 2006.

[15] I. Palaiologou, D. Needham, and T. Male, *Doing research in education: Theory and practice*. Sage, 2015.

[16] J. L. M. Núñez, E. T. Caro, and J. R. H. González, "From Higher Education to Open Education: Challenges in the Transformation of an Online Traditional Course," *IEEE Transactions on Education*, vol. 60, no. 2, pp. 134–142, 2017.

[17] J. Garcia-Zubia, J. Cuadros, S. Romero, U. Hernandez-Jayo, P. Orduña, M. Guenaga, L. Gonzalez-Sabate, and I. Gustavsson, "Empirical analysis of the use of the VISIR remote lab in teaching analog electronics," *IEEE Transactions on Education*, vol. 60, no. 2, pp. 149–156, 2017.

[18] K. E. Hay and S. A. Barab, "Constructivism in practice: A comparison and contrast of apprenticeship and constructionist learning environments," *The Journal of the Learning Sciences*, vol. 10, no. 3, pp. 281–322, 2001.

[19] B. A. Li, "Distributed system educational reform and graduate cultivation of innovative ability," in *Applied Mechanics and Materials*, vol. 263. Trans Tech Publ, 2013, pp. 3435–3438.

[20] S. E. Rodenbusch, P. R. Hernandez, S. L. Simmons, and E. L. Dolan, "Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees," *Cell Biology Education*, vol. 15, no. 2, 2016.

[21] S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth, "Active learning increases student performance in science, engineering, and mathematics," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 111, no. 23, pp. 8410–8415, 2014.

[22] R. Ghannam and W. Ahmad, "Teaching teamwork to transnational students in engineering and technology," in *Compass*, vol. 13, no. 2, 2020. [Online]. Available: https://journals.gre.ac.uk/index.php/compass/article/view/1040

[23] R. Ghannam, S. Hussain, H. Fan, and M. Á. C. González, "Supporting team based learning using electronic laboratory notebooks: Perspectives from transnational students," *IEEE Access*, vol. 9, pp. 43 241–43 252, 2021.

[24] J. Fairweather *et al.*, "Linking evidence and promising practices in science, technology, engineering, and mathematics (stem) undergraduate education," *Board of Science Education, National Research Council, The National Academies, Washington, DC*, 2008.

[25] A. Johri and B. M. Olds, *Cambridge handbook of engineering education research*. Cambridge University Press, 2014.

[26] W. N. Bender, "Project-based learning: Differentiating instruction for the 21st century." *Corwin*, p. 216, 2012.

[27] P. Blumenfeld, E. Soloway, R. Marx, and J. Krajcik, "Motivating project-based learning: Sustaining the doing, supporting the learning," *Educational Psychologist*, vol. 26, pp. 369–398, 11 2011.

[28] C. Guzelis, "Problem based learning versus project based learning in electrical-electronics engineering programs," in *IEEE International Conference on Electrical and Electronics Engineering*, 2012.

[29] C. Stefanou, J. Stolk, M. Prince, J. C. Chen, and S. M. Lord, "Self-regulation and autonomy in problem- and project-based learning environments," *Active Learning in Higher Education*, vol. 14, no. 2, pp. 109–122, 2013.

[30] Z. Zhang, C. T. Hansen, and M. A. Andersen, "Teaching power electronics with a design-oriented, project-based learning method at the technical university of denmark," *IEEE Transactions on Education*, vol. 59, no. 1, pp. 32–38, 2015.

[31] J. Macias-Guarasa, J. M. Montero, R. San-Segundo, A. Araujo, and O. Nieto-Taladriz, "A project-based learning approach to design electronic systems curricula," *IEEE Transactions on Education*, vol. 49, no. 3, pp. 389–397, 2006.

[32] X. Du and J. Han, "A literature review on the definition and process of project-based learning and other relative studies," *Creative Education*, vol. 07, pp. 1079–1083, 2016.

[33] H. Fan, S. Li, S. Yang, Q. Feng, W. Chen, X. Ye, S. Xie, and H. Heidari, "Reform and practice of analog circuits," in *2018 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS)*. IEEE, 2018, pp. 346–349.

[34] L. M. Janssen, V. Flores, and J. Cao, "A north star for gerontology: Using the threshold concept framework to transform ageism education," *The Gerontologist*, 2021.

[35] A. Planas-Lladó, L. Feliu, G. Arbat, J. Pujol, J. J. Suñol, F. Castro, and C. Martí, "An analysis of teamwork based on self and peer evaluation in higher education," *Assessment & Evaluation in Higher Education*, vol. 46, no. 2, pp. 191–207, 2021.

[36] H. Fan, H. Xie, S. Ma, and S. Xie, "Multi-path innovative education for engineering talents," *Research and Exploration in Laboratory*, vol. 40, no. 06, pp. 176–182, 2021.

[37] S. Alapati and S. Yeole, "A review on applications of flex sensors," *International Journal of Emerging Technology and Advanced Engineering*, vol. 7, pp. 97–100, July 2017.

[38] K. Trigwell and M. Prosser, "Development and use of the approaches to teaching inventory," *Educational Psychology Review*, vol. 16, no. 4, pp. 409–424, 2004.

[39] R. A. Berk, "Survey of 12 strategies to measure teaching effectiveness," *International journal of teaching and learning in higher education*, vol. 17, no. 1, pp. 48–62, 2005.

[40] G. L. Connell, D. A. Donovan, and T. G. Chambers, "Increasing the use of student-centered pedagogies from moderate to high improves student learning and attitudes about biology," *Cbe Life Sciences Education*, vol. 15, no. 1, pp. ar3–ar3, 2016.

[41] L. Deslauriers, L. S. McCarty, K. Miller, K. Callaghan, and G. Kestin, "Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom," *Proceedings of the National Academy of Sciences*, vol. 116, no. 39, pp. 19 251–19 257, 2019.

[42] S. Weller, *Academic practice: Developing as a professional in higher education*. Sage, 2019.

[43] P. Kugel, "How professors develop as teachers," *Studies in higher education*, vol. 18, no. 3, pp. 315–328, 1993.

[44] H. E. Academy. Ukpsf (2011) the uk professional standards framework for teaching and supporting learning in higher education. 2022,Feb 12. [Online]. Available: https://www.heacademy.ac.uk/ukpsf

[45] U. DfES, "The future of higher education," 2003.

Hua Fan (M'16) was born in Ziyang, Sichuan, China. She received the B.S. degree in communications engineering and the M.S. degree in Computer science and technology, both from Southwest Jiaotong University, Chengdu, China, in 2003 and 2006, respectively. She received the Ph.D. degree from

Tsinghua University, Beijing, in July 2013. From September 2013 to June 2016, she was an assistant professor of University of Electronic Science and Technology of China. From July 2016 to 2021, she was an associate professor of University of Electronic Science and Technology of China, Chengdu, China. From July 2021 to present, she is a full professor of University of Electronic Science and Technology of China, Chengdu, China.

Huajiang Xie was born in Loudi, Hunan, China, in 1997. He received the B.S. degree in Automation engineering from University of Electronic Science and Technology of China, Chengdu, China in 2019. From August 2019 to present, he is a master student of both KTH Royal Institute of Technology(Kungliga tekniska högskolan),Stockholm,Sweden and University of Electronic Science and Technology of China, Chengdu, China. His main research interest is temperature sensor.

Quanyuan Feng (M'06–SM'08) received the M.S. degree in microelectronics and solid electronics from the University of Electronic Science and Technology of China, Chengdu, China, in 1991, and the Ph.D. degree in electromagnetic field and microwave technology from Southwest Jiaotong University, Chengdu, in 2000. He is currently the Head of the Institute of Microelectronics, Southwest Jiaotong University.

In recent five years, he has authored more than 500 papers such as the IEEE TRANSACTIONS ON POWER ELECTRONICS, IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, and the IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, among which more than 300 were registered by SCI and EI. His current research interests include integrated circuits design, RFID technology, embedded system, wireless communications, antennas and propagation, microwave and millimeter-wave technology, smart information processing, electromagnetic compatibility, and RF/microwave devices and materials.

Dr. Feng has been honoured as the "Excellent Expert" and the "Leader of Science and Technology" of Sichuan Province owing to his outstanding contribution.

Edoardo Bonizzoni (M'06–SM'18) was born in Pavia, Italy, in 1977. He received the Laurea degree (summa cum laude) in Electronic Engineering and the Ph.D. degree in Electronic, Computer, and Electrical Engineering, with a focus on development, design, and testing of non-volatile memories with particular regard to phase-change memories, from the University of Pavia, Italy, in 2002 and 2006, respectively. He is currently an Associate Professor with the Department of Electrical, Computer, and Biomedical Engineering, University of Pavia. He has authored or co-authored over 120 papers in international journals or conferences (with published proceedings) and two book chapters. His current research interests are mainly focused on the design and testing of DC-DC and A/D converters. He focused on single-inductor multiple-output DC-DC buck regulator solutions and on both Nyquist-rate and oversampled A/D converters. His research focuses on the design of high-precision amplifiers and ultra low-voltage reference circuits as well. He was a co-recipient of the IEEE ISCAS 2014 Honorary Mention Paper Award of the Sensory Systems Track, the IEEE/IEEJ Analog VLSI Workshop 2010 Best Paper Award, the IEEE European Solid-State Circuits Conference 2007 Best Paper Award, and the IEEE/IEEJ Analog VLSI Workshop 2007 Best Paper Award. From 2011 to 2015, he served for the IEEE Circuits and Systems Society as an Associate Editor of the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS - PART II. He has been an Associate Editor of the IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS - PART I since 2016.

Hadi Heidari (M'15–SM'17) is an Assistant Professor (Lecturer) and lead of Microelectronics Lab (meLAB) in the School of Engineering at the University of Glasgow, UK. He has authored over 100 publications in peer-reviewed journals and international conferences (with published proceedings). His research on microelectronics design, spintronic sensors and biomedical circuits and systems has received ?m+ funding from various sources, e.g. the EU-H2020 FET-Proactive, Royal Society and EPSRC IAA. He has been the recipient of a number of awards including the IEEE CASS Scholarship (NGCAS'17 conference), Silk Road Award from the Solid-State Circuits Conference (ISSCC'16), Best Paper Award from the IEEE ISCAS'14 conference, Gold Leaf Award from the IEEE PRIME'14 Conference and Rewards for Excellence prize from the University of Glasgow (2018). He involves in the organising committees of the IEEE PRIME'15,'19, SENSORS'16,'17, IEEE NGCAS'17, BioCAS'18, ISCAS'20,'23 conferences and chairing three special sessions at ISCAS'16,'17,'18,'19. He is an IEEE Senior Member, an Editor for the Elsevier Microelectronics Journal, an Associate Editor for the Elsevier Microelectronics Journal, Associate Editor of IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology and IEEE Access, and lead Guest Editor for four journal special issues. He is a member of the IEEE Circuits and Systems Society Board of Governors (2018-21) and a Member-at-Large at the IEEE Sensors Council (2020-21). He is the General Chair of the IEEE International Conference on Electronics Circuits and Systems (ICECS) 2020 in Glasgow.

Michael P. Mcewan is Head of Subject for Academic and Digital Development at the University of Glasgow. His background is in applied mathematics and theoretical physics, and much of his early career was devoted to research in mathematically modelling solar phenomena such as coronal loop oscillations. More recently he taught physics, mathematics and statistics to international pathway students at Glasgow International College which is where his interests in learning and teaching developed. He now leads the PGCAP at the University of Glasgow where he supports the professional development of new teachers in higher education.

Rami Ghannam is an Associate Professor in Engineering Systems Design at the University of Glasgow. He currently serves as IEEE SYSC Distinguished Lecturer. He is also a cross-disciplinary researcher with interests in photonics, sensors and technology-enhanced learning. He leads the "Engineering Design (End) Research Group", which conducts research at the intersection of Human Factors Engineering, Empathetic Computing, Photonics and Sensors. Currently, his research interests are in developing intelligent devices and sensors that enable virtual worlds to exist seamlessly with the real world. Rami Ghannam held previous industrial positions at Nortel Networks and IBM Research GmbH. He is a Senior Member of the IEEE, a Senior Fellow of RET and a Member of the IET. Moreover, he is the Regional Chair of IEEE's Education Society in Scotland and the Chair of the IET Pedagogy in Engineering and Technology TN.