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Teaching Embedded Systems for Energy Harvesting Applications: A Comparison of Teaching Methods Adopted in UESTC and KTH

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ABSTRACT Further to China's plan that was introduced in 2017 for attracting more students into engineering, many Chinese universities have started to explore new teaching methods that can be adopted into their programs. This shift was geared towards developing student-centred teaching materials rather than traditional teacher centred instruction. In this manuscript, we compare two different methods of instruction for a course on energy harvesting using embedded systems. We describe the learning materials and showcase the impact that project-based learning has had on a cohort of Chinese students that were enrolled in a joint master's program between the University of Electronic Science and Technology of China (UESTC) and the Royal Institute of Technology (KTH). KTH has made remarkable progress in the teaching of embedded systems technology for energy harvesting applications, with great emphasis on active as well as collaborative learning. We demonstrate two examples of projects that Chinese students have completed in KTH and present evaluative data regarding their experiences. Our results show that KTH's approach in teaching this module has had a positive impact on student learning, with an average of 80% of students think that teaching in KTH is conducive to students' independent exploration.

INDEX TERMS Embedded system, teaching, project based, experiment, new engineering.

I. INTRODUCTION

The key to the redesign and development of China's engineering education is the training of engineering science research talents and engineering technology talents as well as talents in other fields with engineering backgrounds [1]. Engineering education must prepare students for solving progressive scientific and technological problems [2]. With the gradual application of embedded technology in daily life, we are forced to actively change our embedded system teaching and develop more attractive curriculum models. In recent years, universities have begun to explore new teaching models for keeping in touch with the progress of the society. So far, the embedded systems basically integrate concepts including computer science, software engineering, control systems, and so on [3]. With the limited capacity of finite power sources and the need for supplying energy for a lifetime of a system, a potential and interesting development of embedded systems towards energy harvesting application should be taken into the value.

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In the European higher education system, access to competence is increasingly placed at the center of education [4]. In comparison to China's manufacturing-based economy, Sweden is a "knowledge-based" and "innovative" economy. Its higher education system is one of the most competitive countries in the world [5]. It focuses on developing students' rational thinking ability, and encourages students to continuously innovate and explore [6]. With the continuous promotion of European higher education integration, Sweden has undergone a series of reforms from the degree structure to the curriculum arrangement [7]. The teaching of embedded systems in Sweden has matured in terms of teaching philosophy, teaching system, and curriculum implementation [8].

This article starts from the KTH embedded system experimental course and explores several aspects: First, it summarizes the success of Swedish embedded system teaching; Second, it compares the teaching of embedded system in China and Sweden (UESTC and KTH); Third, combined with the current status of China's current engineering higher education reform, new thinking is proposed for the future embedded system teaching model.

As part of the joint educational program between UESTC and KTH, a number of students (10) took a course on embedded systems in UESTC. We compare and contract their experiences, having taken the same course in KTH.

II. INTRODUCTION TO EMBEDDED SYSTEMS

Embedded systems are centered on "applications" and integrate software and hardware technologies [9]. When designing battery-powered embedded systems, especially wireless networked embedded systems, limited-energy batteries have become a major limiting factor [10]. Using energy harvesting technology instead of traditional power supplies can provide unlimited energy to electronic devices. These embedded systems with energy harvesting have emerged in life: medical implants that collect human energy [11], piezoelectric energy removal systems [12], and so on. Embedded system courses should pay more attention to practical application, which need to combine theory with practice. It involves many basic courses (such as analog circuit foundation, digital circuit foundation, computer system structure, C language, etc.), which makes the teaching of embedded systems complicated. In UESTC, this course is taught during the final year of undergraduate study in the Electronic Engineering degree program.

III. COMPARISON BETWEEN UESTC AND KTH TEACHING OF EMBEDDED SYSTEMS

We first compared with the UESTC teaching of embedded systems with those in KTH. We have focused on the curriculum structure, delivery methods and the assessment techniques used. The following points will be analyzed.

A. TEACHING METHOD

Fig. 1 and Fig. 2 show the structure of how the embedded systems courses are taught in both KTH and UESTC. Among them, the biggest difference between the two institutions is the teaching mode, especially during the preparatory phase of the course.

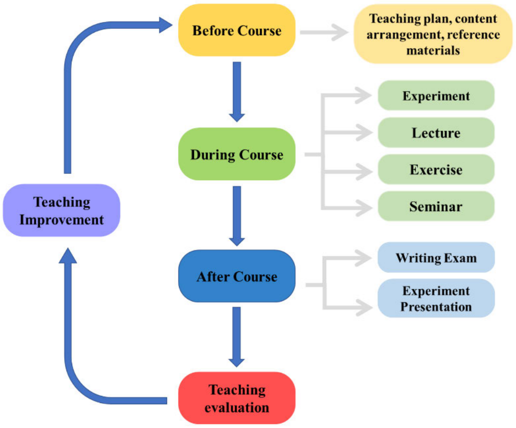


FIGURE 1. KTH teaching structure.

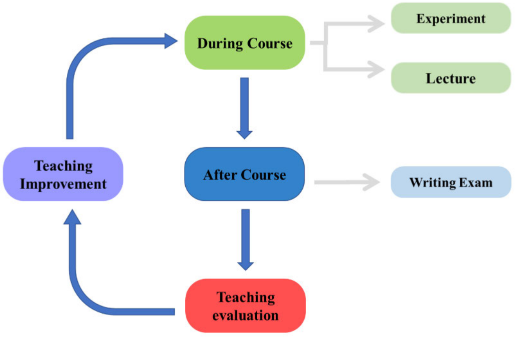


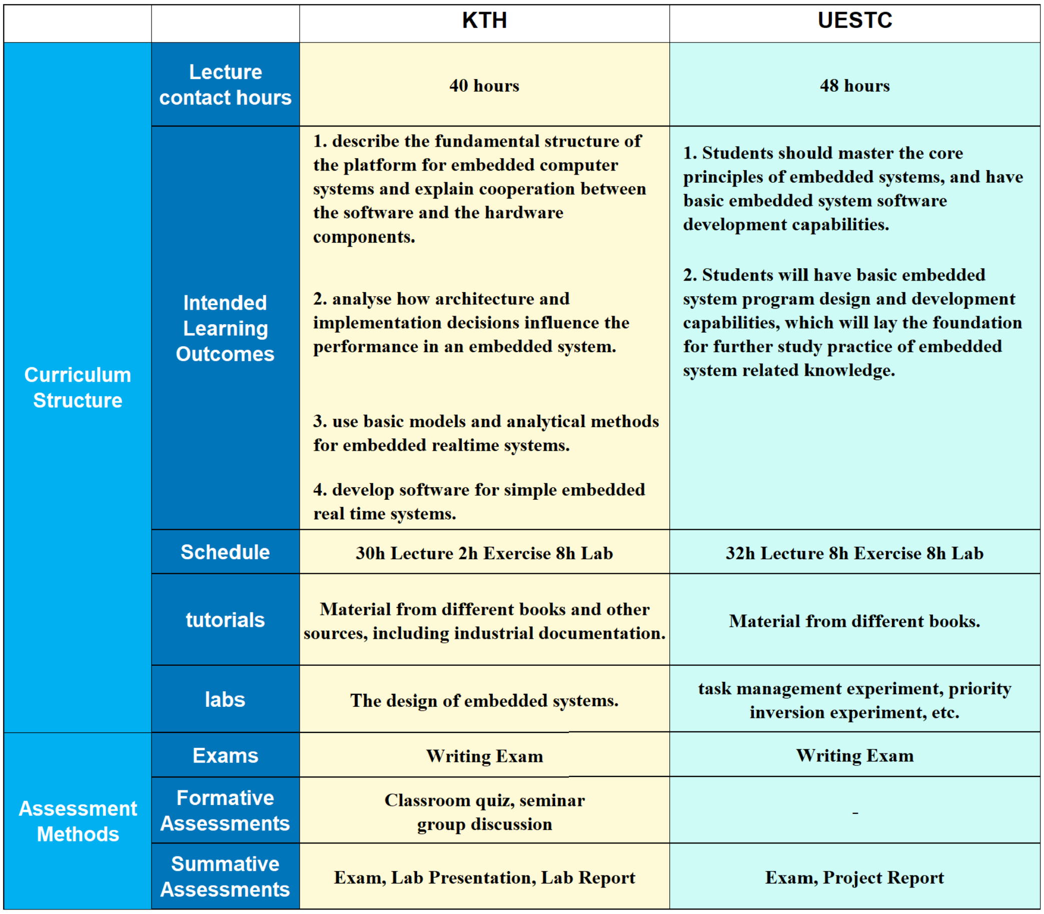
FIGURE 2. UESTC teaching structure.

"Before course" is a very important teaching module in the KTH teaching structure. Teachers often upload course outlines, teaching schedules, and lecture references to the course learning system before the class begins. Therefore, KTH teaching encourages students to prepare for the course in advance. In doing so, students take responsibility for their own learning. Teachers prefer students to come to class with thought rather than listen to lectures [13].

Compared with the Chinese teaching model, we can find that Chinese teaching pays more attention to the knowledge output of teachers and students' knowledge. For example, upon a careful examination of the number of teaching hours, UESTC faculty spend more time delivery content in comparison to KTH. The total number of contact hours in UESTC is 48 hours, in comparison to only 40 hours in KTH. Therefore, 40 hours in KTH corresponds to 7.5 ECTS credits, whereas in UESTC it approximates 9 ECTS credits.

B. CURRICULUM STRUCTURE AND EVALUATION METHODS

Fig. 3 summarizes and compares the differences in curriculum structure and evaluation methods of KTH and



		KTH	UESTC
Curriculum Structure	Lecture contact hours	40 hours	48 hours
	Intended Learning Outcomes	1. describe the fundamental structure of the platform for embedded computer systems and explain cooperation between the software and the hardware components. 2. analyse how architecture and implementation decisions influence the performance in an embedded system. 3. use basic models and analytical methods for embedded realtime systems. 4. develop software for simple embedded real time systems.	1. Students should master the core principles of embedded systems, and have basic embedded system software development capabilities. 2. Students will have basic embedded system program design and development capabilities, which will lay the foundation for further study practice of embedded system related knowledge.
	Schedule	30h Lecture 2h Exercise 8h Lab	32h Lecture 8h Exercise 8h Lab
	tutorials	Material from different books and other sources, including industrial documentation.	Material from different books.
	labs	The design of embedded systems.	task management experiment, priority inversion experiment, etc.
Assessment Methods	Exams	Writing Exam	Writing Exam
	Formative Assessments	Classroom quiz, seminar group discussion	-
	Summative Assessments	Exam, Lab Presentation, Lab Report	Exam, Project Report

FIGURE 3. Differences between the course structure and evaluation methods of KTH (embedded electronic track) and UESTC embedded system courses.

UESTC embedded system courses. KTH's assessment methods includes Formative Assessments and Summative Assessments, while UESTC's course assessment method focuses only on Summative Assessments. Compared with the traditional summative evaluation, formative evaluation can better reflect the whole process of student learning [14]. KTH promotes student-teacher communication through quizzes and seminar in class.

In terms of the curriculum structure shown in Fig. 3, UESTC's current delivery method focuses on traditional methods of teacher-focused teaching. However, this method does not satisfy the needs of industry, where engineers are required to have a solid understanding of science fundamentals, as well as sound communication and problem solving skills [15]. Moreover, experiments were designed to validate a well-bounded problem. Examples of experiments included: task management, priority inversion and semaphore. These experimental projects are not enough to familiarize students with the development process. In other words, the experiments were not designed to simulate real world, unbounded problems. Instead, lab experiments were designed to confirm a certain result. Experimental courses are generally organized step by step. During the experiment, students completed the experiment step by step according to the ideas explained by the teacher and the guidance of the textbook. Such an experiment is difficult to diverge students' thinking on the one hand, and it is difficult to combine it with future research on the other.

On the other hand, the form of teaching in Sweden is more diverse, and its emphasis is also clearer. Lecturers teach the basics, Practice sessions check mastery, seminars explore industry development, and experimental classes apply theory to practice.

IV. COMPARISON OF KTH AND UESTC EXPERIMENTAL MODULES

A. SOFTWARE AND HARDWARE SUPPORT

KTH provides good IT support for students to ensure that students can conduct research studies in the school's computer room or outside the school. In addition, the school also offers a free innovation studio—Mentorspace. It is mainly open to students and employees who wish to work on ideas or project ideas. Fig. 4 is a PCB design project for students in Mentorspace.

FIGURE 4. PCB board design in KTH.

FIGURE 5. Open electronics laboratory in UESTC.

In contrast to KTH's open access policy, UESTC provides restricted access to the IC design laboratory to ensure safety of the students and that equipment is well maintained. The laboratory is equipped with relevant instruments, equipment and computers for design and test. Students can complete the design and debugging of digital and analog circuits (hardware circuits), application circuits, self-made PCB boards and soldering stations. In addition, teachers must be present during the labs to provide tutoring and answering questions during the lab's opening. However, students in KTH must complete the labs independently without direct reliance on the teachers. Fig. 5 shows the microelectronic process equipment of the Electronic Open Laboratory of our university.

B. COURSE IMPLEMENTATION MODE

Aiming at the practical links of embedded systems, the problem of configuration of practical equipment and practical content cannot be ignored [16]. The Chinese experimental course is mainly composed of two parts, namely teacher demonstration and student practice. In order to improve the teaching effect, teachers often demonstrate experiments to students after the introduction of the theory. In the demonstration process, the details and difficulties of the experiment are emphasized. Fig. 6 shows the teacher gives students an experimental demonstration.

In UESTC, experimental and theoretical courses are generally all under the responsibility of a teacher. Due to the large number of students, it is impossible to take care of each classmate in a targeted manner. In contrast, KTH will assign different teaching assistants to help students in theory classes, experimental classes, and exercise classes to answer questions to the greatest extent possible. The content of Swedish experimental courses is often related to real life. This will undoubtedly bring a freshness and appeal to students who are new to this unfamiliar major. The Swedish experimental course is implemented in a cooperative and project-based manner. This encourages students to study independently, collaborate and discuss, and to conduct diversified inquiry into various problems encountered in the experiment, not limited to the experiment itself. Fig. 7 is a scenario where students and assistants discuss with each other in the experimental classroom. Courses in KTH are implemented more closely around working practices and the aim is to promote progress through coordination and cooperation.

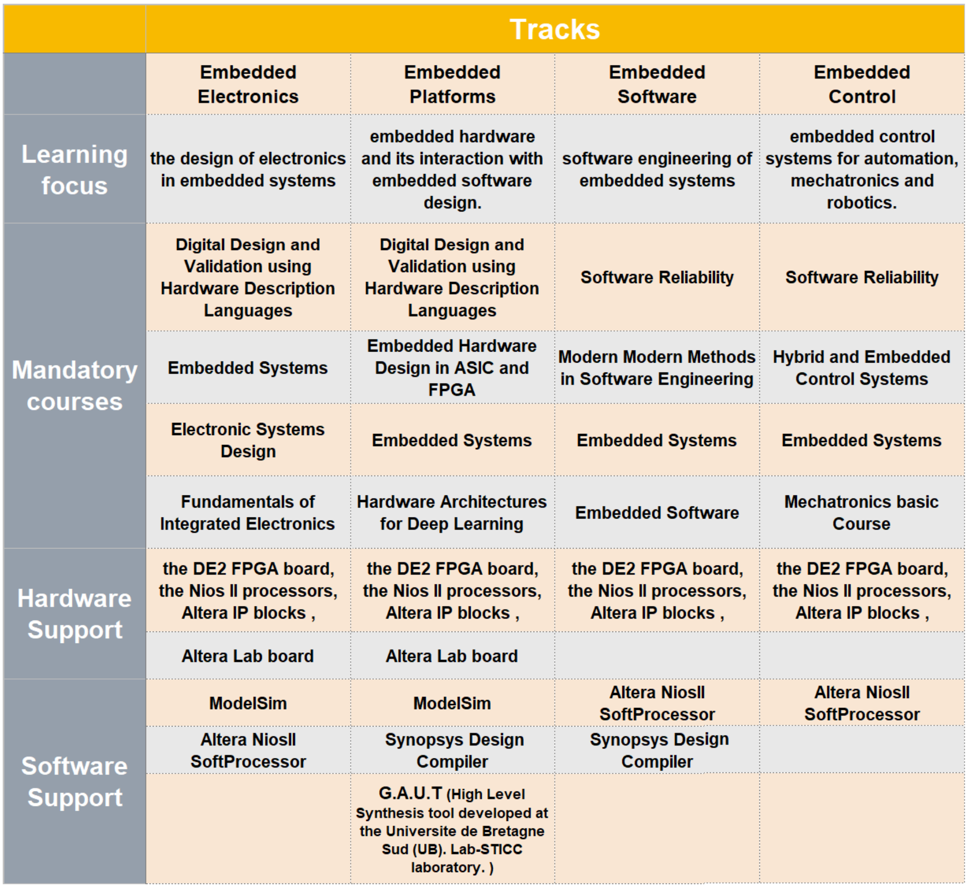
FIGURE 6. Chinese experimental course scene in UESTC.

FIGURE 7. Swedish experimental course scene in KTH.

V. THE SWEDISH EMBEDDED SYSTEM TEACHING

A. ARRANGEMENT OF SWEDISH EMBEDDED SYSTEM COURSE TEACHING SYSTEM

In KTH, embedded systems can be taught differently, depending on the track students are enrolled in. The question is, which components of the course are ‘‘fixed’’ and which ones ‘‘vary’’. There must be a slight difference in the ILOs. The reason why we are highlighting this is to show the flexibility in the KTH method of teaching, in comparison to UESTC's ‘‘fixed’’ method of teaching this course. The teaching of embedded systems in Sweden has matured, and it provides a teaching model for embedded systems that covers the theory and practice of embedded system development. In particular, it emphasizes the application and practice of engineering



	Tracks			
	Embedded Electronics	Embedded Platforms	Embedded Software	Embedded Control
Learning focus	the design of electronics in embedded systems	embedded hardware and its interaction with embedded software design.	software engineering of embedded systems	embedded control systems for automation, mechatronics and robotics.
Mandatory courses	Digital Design and Validation using Hardware Description Languages	Digital Design and Validation using Hardware Description Languages	Software Reliability	Software Reliability
	Embedded Systems	Embedded Hardware Design in ASIC and FPGA	Modern Modern Methods in Software Engineering	Hybrid and Embedded Control Systems
	Electronic Systems Design	Embedded Systems	Embedded Systems	Embedded Systems
	Fundamentals of Integrated Electronics	Hardware Architectures for Deep Learning	Embedded Software	Mechatronics basic Course
Hardware Support	the DE2 FPGA board, the Nios II processors, Altera IP blocks ,	the DE2 FPGA board, the Nios II processors, Altera IP blocks ,	the DE2 FPGA board, the Nios II processors, Altera IP blocks ,	the DE2 FPGA board, the Nios II processors, Altera IP blocks ,
	Altera Lab board	Altera Lab board		
Software Support	ModelSim	ModelSim	Altera NiosII SoftProcessor	Altera NiosII SoftProcessor
	Altera NiosII SoftProcessor	Synopsys Design Compiler	Synopsys Design Compiler	
		G.A.U.T (High Level Synthesis tool developed at the Universite de Bretagne Sud (UB). Lab-STICC laboratory.)		

FIGURE 8. Summary comparison of four different tracks.

skills such as software and hardware integration, system design, integration, and verification. Therefore, embedded systems courses are an essential part. As shown in Fig. 8, four tracks are provided for students to choose from: embedded electronics, embedded platform, embedded control, and embedded software.

For different tracks, corresponding compulsory and elective courses have been set. Each course consists of lectures, experiments, seminars, and exams. The courses are diverse in structure and rich in content, thus avoiding single teaching styles and dull classrooms. In addition to the basic knowledge, the lectures also share the latest technology explorations for the current industry. The experiments are mainly done through cooperative inquiry. The greatest benefit to students in this way is to stimulate thinking through interaction, which is conducive to finding problems and solving problems. Under the guidance of the professor, the seminars focused on the hot topics of the current industry in groups and around the topics.

B. THE CHARACTERISTICS OF SWEDISH EMBEDDED SYSTEM PROFESSIONAL TEACHING

The teaching system of KTH embedded system specialty always revolves around ''freedom'' and ''cooperation''.

a: SEMINAR

In addition to developing student technical skills, the KTH course helps improve student soft skills, such as communication and digital literacy. This teaching mode is still relatively unfamiliar to domestic universities, and foreign universities have matured. The seminar will determine the subject matter in advance, and students will prepare in advance. Seminars are mainly group discussions, and each student is required to present his or her own opinion. Finally, under the guidance of the professor, the students discussed in their respective groups. In this model, collaborative inquiry promotes interactivity among students.

b: PROJECT BASED EXPERIMENT

It is mainly carried out by project based experiments [17]. Fig. 9 shows the basic process of KTH inquiry cooperation experiment.

Students are grouped freely, and students have a large degree of freedom. Under the given experimental requirements, in addition to completing the experiments on their own, students must expand and explore the problems encountered in the experiments. On the one hand, experiments encourage students to collaborate and study independently, and on the other hand, divergent inquiry into various

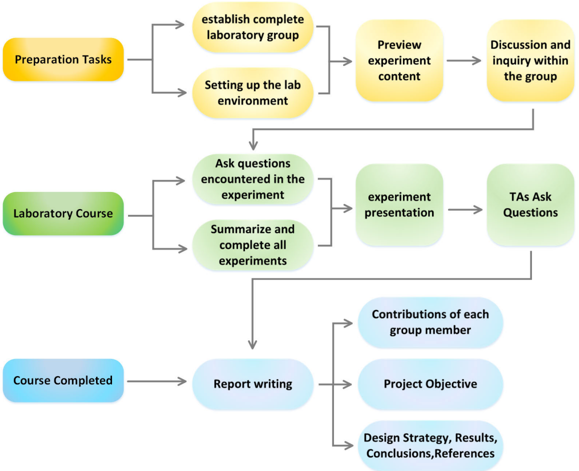


FIGURE 9. KTH inquiry cooperative experiment flow chart.

problems encountered in experiments is no longer limited to the experiments themselves. In the next section we will briefly describe the type of project based experiments that students are required to complete.

VI. EXAMPLES OF PROJECT BASED LEARNING IN EMBEDDED SYSTEM EXPERIMENTAL COURSE

In embedded system teaching, it often appears that the theoretical knowledge acquired by students is sufficient, and their practical skills still have many shortcomings [18]. In the setting and selection of experimental items, the continuity and flexibility of theoretical knowledge have been fully considered. While ensuring the professionalism and effectiveness of the project, ensure that the experiment has certain flexibility to help students have enough space for diversification and inquiry. The following will specifically analyze two actual project cases.

A. PROJECT EXAMPLE 1: ANALOG REAL-TIME CAR CRUISE SYSTEM

At present, family cars are generally equipped with a energy harvesting vehicle cruise system. On the one hand, energy harvesting vehicle cruise system can effectively reduce fuel consumption. By reducing the emission of harmful gases, it saves energy and reduces emission [19]. On the other hand, it also reduces frequent operations by the driver. Therefore, the wear of automobile mechanical components is reduced, as well as the frequency of failures will be decreased. The purpose of this lab is to enable students to gain hands-on experience with real-time operating systems and to develop real-time applications on a typical real-time operating system (μC/OS-II embedded system) using the DE2 development board to design a simulated car cruise control system. In this experiment, students should deepen understanding of intermediate links (such as semaphores, mailboxes, and message queues) based on a basic understanding of real-time operating systems (RTOS), and implement applications through synchronization and communication between multiple tasks.

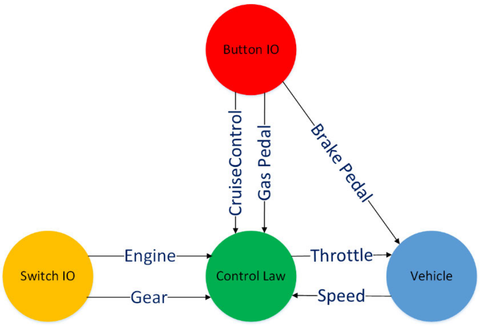


FIGURE 10. Basic cruise system function diagram.

Fig. 10 shows the functional schematic of the basic cruise system. Students need to complete the initialization algorithm and write code to implement the vehicle task and control task procedures in the complete cruise system. The system includes five input signals: engine start, cruise control, brake pedal, brake pedal, and gear. These input signals are equivalent to control switches in an actual cruise system. By controlling these five input signals, the on-off state of the engine is realized; the car cruise function is turned on or off; the throttle is controlled to achieve acceleration and the brake is controlled to achieve deceleration; and the car gear is selected. Among them, these five input signals affect each other during the cruise system operation.

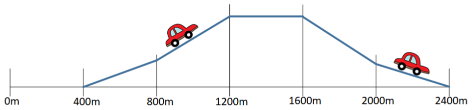


FIGURE 11. Schematic diagram of the current position of the basic cruise control system.

In addition, as shown in Fig. 11, the system should also measure the current position of the car (whether it is uphill or downhill or flat road) and current speed. This requires students to fully understand the current driving state of the car, use the basic knowledge of physics, consider the acceleration due to different wind speeds when going up and down the slope, and finally derive the expression formula for speed and position.

In this cruise system, there are many events and the communication between events is complicated. Therefore, for such a multitasking operating system, it is necessary to master the synchronization and communication between tasks. In the application of this system, we hope that students can communicate with each task by using semaphores, mailboxes, and message queues to identify the differences between the three.

Fig. 12 shows the basic cruise control system implemented on the DE2/DE-115 development board. Students can adjust the speed of the car by adjusting three buttons and two switches. And when the speed at the moment of performing the cruise operation is greater than 20 m/s, the cruise function can be achieved (that is, the vehicle speed is stable).

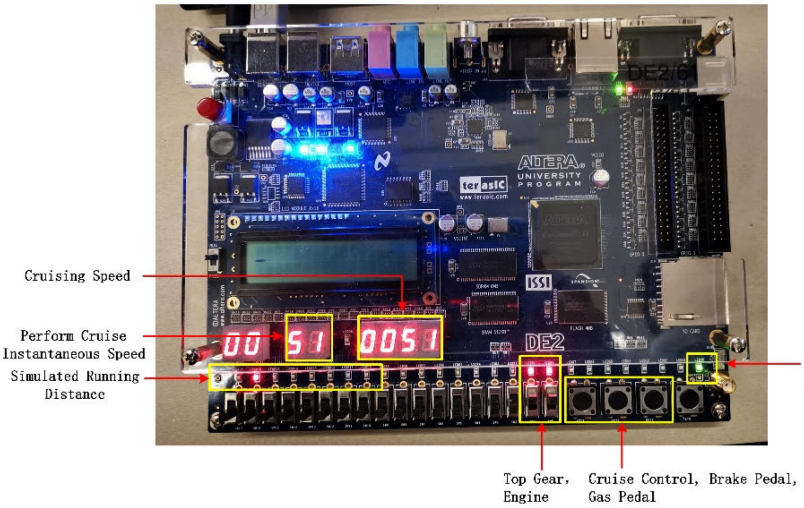


FIGURE 12. Implementation of basic cruise control system on DE2 Board.

In Fig. 12, the cruise indicator light is on, the cruise speed is maintained at 51 m/s, and the running distance of the vehicle can be displayed by assigning different LEDs.

B. PROJECT EXAMPLE 2: APPLICATION OF IMAGE TRACKING ALGORITHM

The magnetic sensor collects the magnetic field energy information around the environment and displays it in the form of a magnetic field energy distribution map. An embedded image tracking system can be used to analyze magnetic field energy information, which is helpful for the research of magnetic field energy collection devices. The project requires an image tracking algorithm to be implemented on a multi-processor hardware platform on a DE2 development board in a multi-core with non-operating system. The algorithm tracks moving "round" patterns in a series of (given) image frames.

The input image is stored as a pixel array in the SRAM on the DE2 development board. The output of the application is an array of coordinate pairs for each input image, corresponding to the X and Y positions of the identified image pattern, and also stored in the SRAM on the DE2 development board.

The project first requires an understanding of the application's execution flow. The execution process is modeled and implemented in Haskell language. The application model is represented by the synchronous data flow model (SDF) shown in Fig. 13. Synchronous data flow (SDF) is a constrained form of data flow in which, for each participant, each trigger consumes a fixed number of input tokens on each input port and generates a fixed amount on each output port Number of exit tokens [20].

The entire application needs to implement 7 models: graySDF, cropSDF, xcorr2SDF, getOffsetSDF, calcCoordSDF, calcPosSDF, and delaySDF.

The hardware platform provided by this project is shown in Fig. 14. It contains five 32-bit CPUs, and each CPU contains a 4 KB instruction cache and a 2 KB data cache.

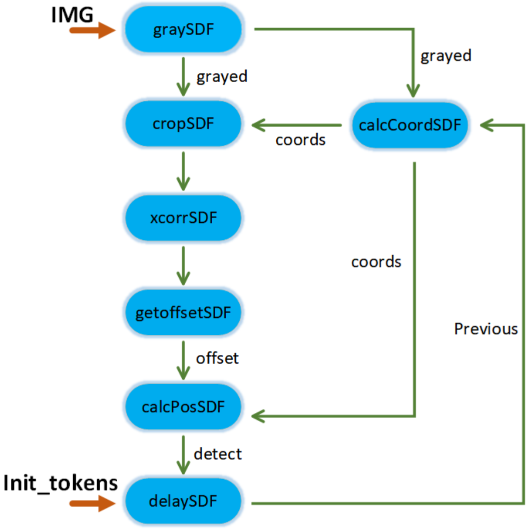


FIGURE 13. The diagram of synchronous data flow.

Among them, only CPU0 can access SRAM and SDRAM, and there is no on-chip memory. The remaining 4 CPUs all have 8192 bytes of on-chip memory that can access shared on-chip memory. Mutex ensures that only one thread can run simultaneously. FIFO is a register that first implements data output. When multiple masters want to access a slave, the arbitration scheme will help determine which master has the higher access priority.

In this multi-core with non-operating system, CPU0 is the master processor and CPU1, 2, 3, 4 are slave processors. This structure enhances hardware performance and processing power. Each slave CPU can process part of the image on its own on-chip memory. CPU0 takes the starting point and crops the original image, then stores it in shared memory. CPU1-4 read the 0.25 cropped image from the shared memory, and

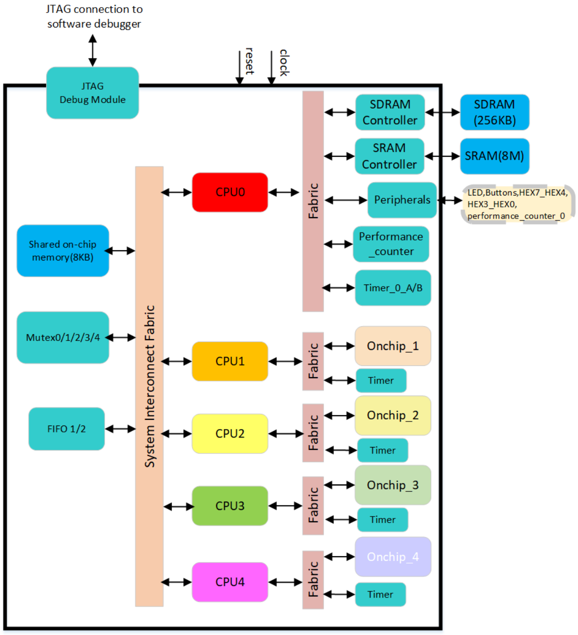
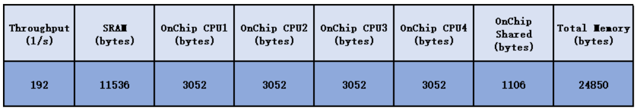


FIGURE 14. Multiprocessor platform architecture.



Throughput (1/s)	SRAM (bytes)	OnChip CPU1 (bytes)	OnChip CPU2 (bytes)	OnChip CPU3 (bytes)	OnChip CPU4 (bytes)	OnChip Shared (bytes)	Total Memory (bytes)
192	11536	3052	3052	3052	3052	1106	24850

FIGURE 15. Image tracking application test results.

then performs grayscale processing on it to obtain the target point. They then store the coordinates in shared memory. Finally, CPU0 will get the coordinates and output it. The final experimental test results are shown in Fig. 15. It can be seen that the image tracking application implemented on a multiprocessor platform can reach 192 pictures per second (all the pictures are specific pictures for the experiment). The total code footprint is 24.85 Kbytes.

In the multiprocessor environment required by the project, how to access and allocate shared resources will be a question for students to explore further. This is because when multiple processors want to use the same bus, only one peripheral can put data on one bus at a time. In addition, because of the limited resources of multiprocessors, code and board/compiler optimizations need to be explored.

Although multiprocessors have great advantages in improving the efficiency of applications, the parallelism of the processors should be considered. Students need to explore how to use mutex locks to prevent CPU interleaving so that all CPUs can access shared memory in an appropriate manner. In addition, students should collaborate to explore code optimizations. For example: use the shift operator to implement the multiplication function; use Int pointers instead of unsigned char pointers to improve data transfer and so on.

VII. RESULTS AND DISCUSSION

We investigated differences in teaching and delivery methods for the same course.

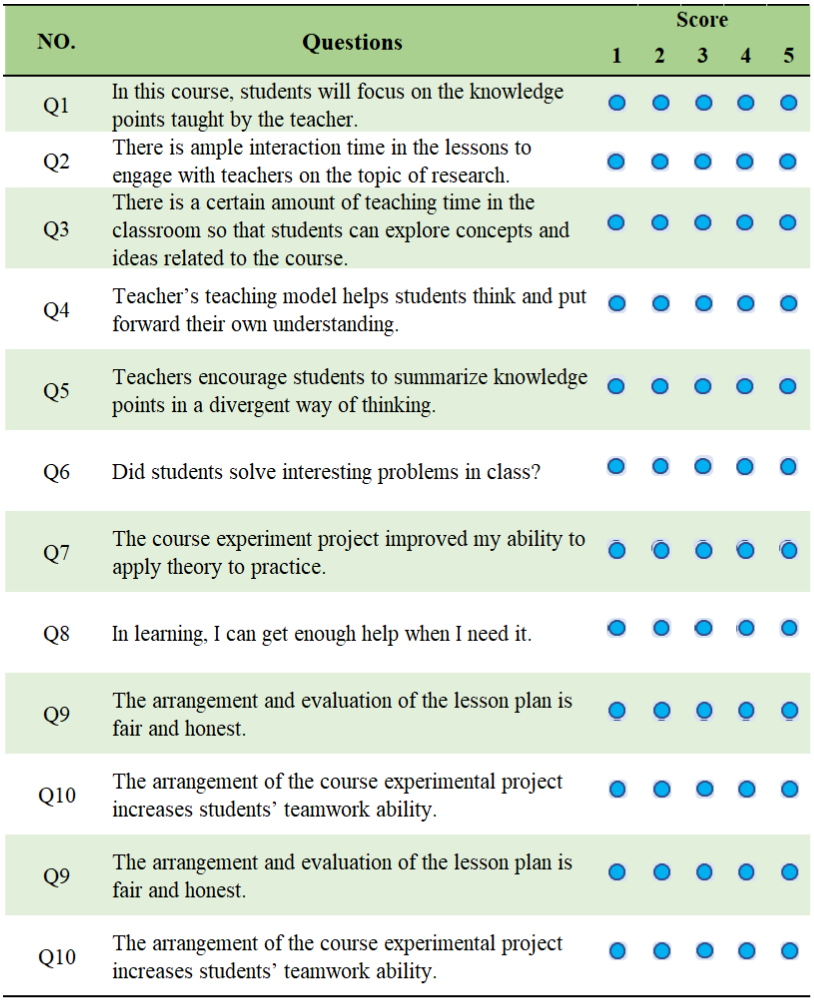
Teaching evaluation is a link that cannot be ignored in the entire teaching system. It plays a role in promoting teachers' self-regulation and students' self-regulation [21]. Teaching assessment provides teachers with the most authentic teaching information, so that problems in teaching can be corrected in time.

We conducted the same teaching evaluation analysis on 10 students in Sweden (2 females and 8 males) with the same 10 students in China (2 females and 8 males), and compared and analyzed the results. The teaching assessment consisted of two parts: the estimated study workload and the learning experience. The teaching evaluation embodies the teaching's emphasis on teacher-centered knowledge transfer or student-centered inquiry learning. Fig. 16 shows the content of some assessment forms. Questions 1-5 focus on teacher teaching; Questions 6-10 focus on student learning. Each question and answer option have a total of 1 to 5 representing different levels of feedback from low to high. 1 represents little or no recognition; 5 represents greater than 90% recognition. We analyze the results by scoring 1-5 and 6-10, and comparing the scores.

Fig. 17 shows a comparison of the estimated workload based on feedback from Chinese and Swedish students. Among them, we can see that more than 80% of students in UESTC and KTH study more than 12 hours per week. Among them, nearly 50% of students in Sweden study more than 18 hours per week, and 30% of students study more than 21 hours. Compared with China, only 20% of students study for more than 18 hours per week. Taken together, Swedish students spend an average of 17.2hours per week studying 14.7 hours more than Chinese students. Swedish students spend more time on experimental inquiry, that is, the practical application of knowledge points. This is different from the phenomenon that Chinese students only pay attention to the knowledge of textbooks.

Fig. 18 shows a comparison of teaching quality assessment results between China and Sweden. In general, whether in UESTC or KTH, students have a positive attitude towards the quality of teaching in the subject.

The evaluation data were statistically averaged according to the three categories of "agree", "neutral" and "disagree". Among them, "agree" includes strongly agree and agree, and "disagree" includes strongly disagree and disagree. Fig. 19 depicts the corresponding statistical results. By comparison, evaluations (Q1-Q5) around teacher teaching show that 72% of students studied in UESTC have exceeded 68% of KTH students' approval (including strongly agree and agree): teachers play a core role in the overall teaching, and teachers will spend more time in the classroom on teaching tasks. The comparison of Q3 evaluation is the most obvious. Nearly 90% of students agree that UESTC teachers have enough time to teach knowledge in the classroom, while



NO.	Questions	Score				
		1	2	3	4	5
Q1	In this course, students will focus on the knowledge points taught by the teacher.	●	●	●	●	●
Q2	There is ample interaction time in the lessons to engage with teachers on the topic of research.	●	●	●	●	●
Q3	There is a certain amount of teaching time in the classroom so that students can explore concepts and ideas related to the course.	●	●	●	●	●
Q4	Teacher's teaching model helps students think and put forward their own understanding.	●	●	●	●	●
Q5	Teachers encourage students to summarize knowledge points in a divergent way of thinking.	●	●	●	●	●
Q6	Did students solve interesting problems in class?	●	●	●	●	●
Q7	The course experiment project improved my ability to apply theory to practice.	●	●	●	●	●
Q8	In learning, I can get enough help when I need it.	●	●	●	●	●
Q9	The arrangement and evaluation of the lesson plan is fair and honest.	●	●	●	●	●
Q10	The arrangement of the course experimental project increases students' teamwork ability.	●	●	●	●	●
Q9	The arrangement and evaluation of the lesson plan is fair and honest.	●	●	●	●	●
Q10	The arrangement of the course experimental project increases students' teamwork ability.	●	●	●	●	●

FIGURE 16. **Teaching evaluation form.**

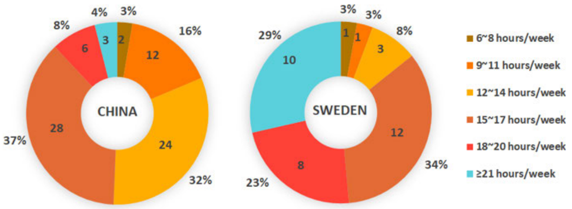


FIGURE 17. **Comparison of workload results between China and Sweden.**

only 40% of students in Sweden agree, and no one even strongly agrees. From the evaluation of Q6-Q10, it can be seen that an average of 80% of students studied in KTH and 38% of students studied in UESTC think that teaching is conducive to students' independent exploration, and advocate the cultivation of "theory applied to practice". Some students in Sweden said, "This course provides students with a lot of learning support to ensure that we can be helped at all times, which greatly increases the value of learning and is a great learning experience." In general, Chinese teaching places more emphasis on the classroom, and teaching is centered on "teachers". Sweden places greater emphasis on "inquiry" and encourages students to explore independently.

And it is very difficult for students to fully understand the knowledge points and master the practical application in the course of just a few dozen hours.

Typical engineering courses in doctorate granting institutions are taught using the bottom-up teaching philosophy [22]. This includes teaching embedded systems [23]. Therefore, the teacher first introduces the students to the bit-level microcontroller, and then to the operating system level. However, engineers in the real-world typically encounter or deal with problems that are ill-bounded and do not have a single solution. Furthermore, workplace problems are interdisciplinary in nature. Consequently, the typical worked examples provided to engineering students in UESTC do not prepare graduates to real world engineering problems.

According to the experimental project of the KTH embedded system experiment course, we can find that the KTH

NO.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Q1	6	3	1	0	0
Q2	1	2	6	1	0
Q3	7	2	1	0	0
Q4	3	3	2	2	0
Q5	6	3	1	0	0
Q6	0	1	6	3	0
Q7	2	2	4	1	1
Q8	1	2	2	3	2
Q9	2	1	5	2	0
Q10	5	3	1	1	0

NO.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Q1	5	5	0	0	0
Q2	5	0	5	0	0
Q3	0	4	2	3	1
Q4	0	7	2	1	0
Q5	4	4	0	2	0
Q6	2	5	3	0	0
Q7	5	5	0	0	0
Q8	0	5	5	0	0
Q9	2	6	2	0	0
Q10	8	2	0	0	0

FIGURE 18. **Comparison of evaluation results between China and Sweden.**

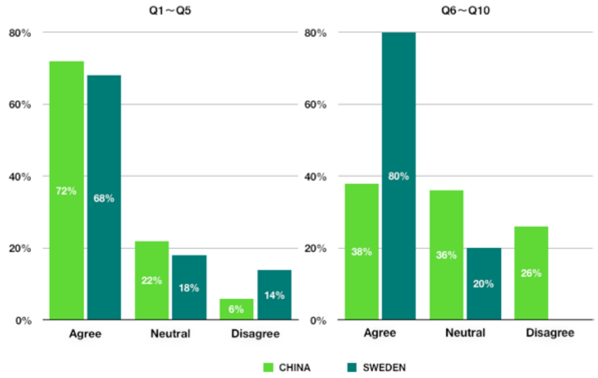


FIGURE 19. **Comparison chart of average student evaluation results.**

teaching of embedded system makes full use of hardware and software resources, and emphasizes the ''inquiry'' of the course. The content of the course is diverse, uncertain, and innovative, and emphasizes the divergence and thinking of students about knowledge points.

VIII. CONCLUSION

Due to the late development of embedded systems in China, the rapid development of embedded systems in recent years has reduced the degree of optimization of embedded system teaching, and the following problems exist: 1. What are the theoretical and practical aspects of future embedded system teaching Collaborative exploration? 2. How to enhance students' experimental operation ability, encourage students to think freely, try different thinking and solve problems? 3. We need to reform the curriculum assessment model to meet the needs of students in all aspects of learning.

We therefore recommend using the project-based learning technique, since this is closely aligned with the way engineers work in the real-world. Our exchange students have indicated a strong preference to the teaching methods adopted in our partnering institute in Sweden. Our results show that the cooperative PBL approach is helpful to the overall teaching and improves the disadvantages of the traditional focus on knowledge output and the actual situation of students. At the same time, the combination of multiple assessment modes enables the teacher to always grasp the students' learning situation in the overall teaching. Consequently, this case study shows our motivation to adopt this method in our teaching practice.

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