Teaching Reform and Practice Using the Concept of Outcome-Based Education – A Case Study on Curriculum Design for a Microcontroller Unit Course

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Abstract—Foundation and Application of Microcontroller (FAoM), a theoretically and practically important specialized course for automation majors, is interdisciplinary and has a wide range of instructional content. Conventional teaching methods center on the needs of teachers but do not prioritize fostering practical skills and innovation capacity. This split focus tends to neglect the achievement of learning outcomes and causes deficiency in practice ability. Therefore, instructional reform oriented toward outcome-based education (OBE) was proposed in this study to promote endogenous motivation to learn and enhance effectiveness and flexibility in practical teaching by subdividing instructional objectives, rearranging instructional contents, conducting modularized teaching, and formulating typical tasks. To evaluate the performance of the instructional reform based on OBE, students were engaged to develop a temperature measurement system with knowledge they learned by using software Keil, Proteus, and Altium. Statistics show that the proposed methodology exceeds the traditional method of teaching in all six evaluation indexes, achieving the student-centered curriculum objective. The implementation of the reform on FAoM is of considerable importance for students. They benefit from immersive teaching, broadening their minds and cultivating their capacity to address practical engineering problems.

1 Introduction

Foundation and Application of Microcontroller (FAoM), a core course adopted in many engineering specialties, has a firm theoretical basis and practicality. The microcontroller unit (MCU) is widely used in many fields, such as consumer electronics, medical equipment, industrial control, instrumentation, and military affairs. Extensive support from MCU manufacturers has strongly promoted the update and advancement

of electronic devices in a plethora of industries, entailing professional skills for those in automation-related domains [1]. With knowledge of system architecture learned from FAoM, students are expected to be able to obtain a clearer understanding of how MCU can be applied in industrial and civil construction, grasp the process of hardware and software design at the system level, and formulate research and development programs for complex embedded control applications. Thus, the experience of developing MCU electronic products will establish a solid foundation for students to enhance their career competitiveness and engagement with designing, testing, and maintaining advanced equipment in the future.

In the traditional mode of MCU teaching, due to the equivocal training objective and a finite pool of teaching methods, teachers tend to deliver only theoretical knowledge in class, causing the following problems [2][3][4]. (1) Students are expected to carry out learning activities according to the well-established teaching plan and schedule stated in curriculum standards, but the fundamental goal for teaching, that is, learning outcomes, is ignored. (2) In the knowledge-orientated mode of teaching, which lacks the cultivation of practical skills and innovation capabilities, teachers focus on the achievement of theoretical curricular contents while students worry about learning to the final exams and study only for a desired score. (3) Teacher-centered, rather than student-centered instruction and classroom management neglects the concept of collaboration, and fostering students to work together for the spirit of excellence is difficult. (4) Assessments are in many cases summative, not formative or self-explanatory, and they lack a combination of multiple measures in assessment from the perspective of the learning process.

Educationalists consider that this style of teaching and learning introduces difficulties in combining theory with practice, potential mismatches between instruction and capacity promotion, and burdens for students to acquire knowledge [5]. The concept of outcome-based education (OBE), with a student-centered and outcome-oriented purpose, is introduced into the teaching process of FAoM, enabling students to obtain learning interests and solve practical issues.

2 State of the art

In recent years, explorations and research on the curriculum architecture, instructional content, teaching method, and assessment scheme of FAoM have been conducted broadly. Zhao et al. [6] put forward innovative opinions, such as learning interest, knowledge structure, and capacity promotion, that foster teaching methods. Unfortunately, discussions on how the effect of teaching was improved have been very few. Luis et al. [7] presented the essential methods for aerospace engineering students to keep quality standards by using blended learning during the COVID-19 pandemic. The use of digital resources and educational platforms caused a noticeable change in the students' way of learning and improved learning habits and digital skills. However, the concept of OBE was not involved. Chrysi et al. [8] provided some expert insights into online-learning-related pedagogical content knowledge. The findings indicated the design of learning activities with certain characteristics, the combination of three types of

presence (social, cognitive, and facilitatory), and the need for adapting assessment to the new learning requirements. Under the background of professional certification, Du [9] formulated a detailed curriculum objective and corresponding assessment method of student achievement, enabling teachers to identify the extent to which students attained their educational goals through analyses of the achievement of curriculum objectives, improving the effect of teaching continuously. Pi et al. [10] suggested a reform of instruction and practice with respect to methods of teaching, assessment, school-enterprise cooperation, innovation, and system of practice. This reform is aimed at reinforcing students' capacity for innovation, practice, and knowledge integration. However, the use of only traditional methods of teaching (e.g. PowerPoint) focused excessively on theory instead of practice. This dearth of practice tends to cause a dilemma of knowledge in students when they practice a given skill. Wu et al. [11] designed and implemented a reform for FAoM with an instructional platform called "Rain Classroom," in which the teaching process consisted of three parts, i.e., pre-class preview, in-class teaching, and out-of-class analysis. The students' enthusiasm and initiative for learning were enhanced and academic performance was improved. However, continuous improvement was not considered in this type of teaching mode. To train outstanding MCU engineers, Lin [12] explored the teaching reform based on conception, design, implementation, and operation from the perspective of knowledge structure, instructional content, method, and evaluation, laying a solid foundation for students to overcome their employment pressure. Metri et al. [13] introduced a project-based learning (PBL) approach where four learning activities were considered, i.e., lectures-discussions, program demonstration, project presentation, and project execution. Students were asked to choose their own design topic for their team project, using minimum guidelines provided by the course instructor. They were encouraged to accomplish the project autonomously with self-learning and peer-coaching. Evaluation of this practice was obtained from students, staff, and an external examiner, and the results showed that the PBL achieved its educational objectives. Rojas et al. [14] presented how modular design techniques aided by an OBE framework can be incorporated in an embedded systems design laboratory. The laboratory objectives and contents, pedagogical methods, and assessment activities were aligned using an OBE framework to ensure proper student learning. Pulavarthi et al. [15] proposed continuous assessment and course-mini projects (CMPs) to attain graduate attributes in engineering education programs. The study showed that students' skillsets can be improved by involving students to work on community-based or industry-related real-time CMP. However, such assessment failed to cover the instructional process systematically and comprehensively.

To address problems of teaching in engineering specialties such as ambiguous instructional objectives, absence of practice, dislocation of teaching and learning, and lack of assessments, a reform on the course FAoM of North Sichuan Medical College (NSMC) was conducted. The concept of OBE was introduced to carry out student-centered and outcome-oriented instructional reform following the entire teaching process. According to the instructional objectives of this course, explicit curriculum contents were formulated and divided into modules and themes, with corresponding points of core knowledge highlighted. A model of evaluation with multiple forms of assessment

was established to quantify the degree of achievement of hands-on projects. Thus, all participants will have a clear understanding of the progress.

3 Educational concept and instructional design based on OBE

3.1 OBE

OBE is an educational theory that bases each part of an educational system around goals. As an advanced educational philosophy, the concept of OBE was first proposed by Spady [16] and quickly elicited widespread attention from the education community. OBE has become the mainstream of education reform in countries such as the United States, the United Kingdom, and Canada. By the end of the educational experience, each student should have achieved an explicit goal. The focus is on what students can do after receiving education. No single style of teaching or assessment is specified in OBE. Instead, classes, opportunities, and assessments should all help students achieve the specified outcomes. The role of the faculty adapts into instructor, trainer, facilitator, and/or mentor based on the outcomes targeted.

The concept of OBE follows the principle of backward design and forward implementation, emphasizing the hierarchies and connections between desired learning outcomes. In backward design, the teacher starts with needs (the needs of education, society and country, educational orientation, expectations from alumni and parents, and the requirements for the development of industry and occupation), creates training objectives, sets graduation requirements, and makes a curriculum system. In this case, the needs (destination) are chosen first and then the rest of the nodes are linked one by one to reach the curriculum system (start). Afterward, the curriculum design can be implemented inversely according to the "route map" formulated. In this context, the needs act not only as the start of education but also the destination, greatly facilitating consistency between educational objectives and outcomes.

3.2 Instructional design based on OBE

Instructional design under the OBE-based pedagogical mode follows three core principles, i.e., student-centralization, outcome-orientation, and continuous improvement. Teachers using the concept of OBE need to rearrange syllabuses and points of knowledge, reorganize instructional activities, and develop instructional planning that guide theoretical and practical classes. Figure 1 illustrates the process of the instructional design based on OBE. Course objective, course content, course implementation, course assessment, course evaluation, and continuous improvement comprise the major framework, which rotates counterclockwise around the center of student-centralization. In this closed-loop system, the course objective acts as the start and end points, clearly reflecting the desired learning outcomes of students.
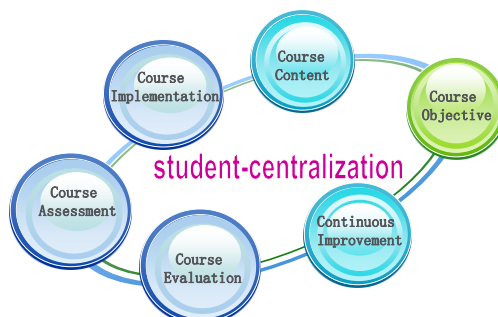
Fig. 1. Diagram of instructional design

In these elements of instructional design, the course objective, the most important part, focuses on developing comprehensive capacities of students and includes students' desired learning outcomes as part of itself. To provide teachers with support about how the graduation requirements are achieved through the completion of the objectives, the description of the course objective should embody the takeaway of, and corresponds to, the graduation requirements. The course content can be formulated distinctively according to the extent to which the course objectives are achieved in terms of knowledge, capacity, and quality. If the learning outcome is expected to be attained precisely, the course content needs to coincide with the course objective explicitly. Aiming to strengthen the comprehensive qualities of students and train innovative talents, teachers are naturally allowed to choose teaching methods independently in the course of implementation, in compliance with government policies, industry needs, and characteristics of institutions. The traditional course assessment emphasizes excessively the systematicness and unity of knowledge, decreasing performance of developing capacities in quality improvement. Such assessment also lacks effectiveness in monitoring the learning process. By contrast, in the outcome-based model, methods of assessment are formulated specifically for instructional objectives. These methods should be conducive to identifying the achievements of the course objectives for all students and ought to reflect factors of competency promotion required by the course objectives. The OBE-based course evaluation aims to collect students' learning outcomes and objectively estimate completion rates of course objectives that correspond to the graduation requirements. Last, continuous improvement refers to an ongoing procedure that dynamically improves course objectives, course contents, teaching strategies, and assessment methods with the goal of improving outcomes and experiences for future students.

4 Practice of reform for OBE-based curriculum design on MCU

The implementation of the Educational Program of the Research and Reform of North Sichuan Medical College 2021 integrated the elemental factors discussed above (i.e., course objectives, course contents, course implementation, course assessment,

course evaluation, and continuous improvement) with the experiences derived from teaching FAoM. The idea of curriculum reform for Curriculum Design for MCU (CDMCU) is therefore organized as follows.

4.1 Course objective setting

CDMCU, which is an important course to train students to apply the professional theoretical knowledge they have learned to solve practical engineering problems, is also considered as an extension and subsequence of FAoM. CDMCU aims to provide students with a "workshop" to cultivate practical and hands-on skills. By referencing training goals and graduation requirements of relevant specialties, the new course objectives of CDMCU are proposed, and the corresponding relationships between these outcomes and graduation requirements are shown in Table 1.

Table 1. Course objectives and graduation requirements

Course Outcomes (COs)	Graduation Requirements
COs1: Master the development status and trend of MCUs by accessing electronic information (e.g., via literature survey)	Analyze engineering problems in electronic science and technology through literature review and obtain valuable conclusions.
COs2: Formulate a technical route for research on MCU-based electronic devices and prepare curriculum design reports using skills of software and hardware development.	Provide original solutions to practical engineering problems and build fundamental circuits, software systems, and process flows for specific purposes.
Cos3: Design MCU products with knowledge of physical components encompassing hardware architectures, I/O ports, timers/counters, interrupt systems, serial ports, and digital/analog converters.	Apply knowledge of mathematics, natural sciences, and engineering foundations to address engineering problems in electronic science and technology.
COs4: Simulate and debug the control system using toolkits such as Keil and Proteus and design printed circuit boards (PCB) with electronic design automation software such as Protel and Altium Designer.	Choose, utilize, and develop appropriate technologies, resources, and modern engineering tools for prediction and simulation in electronic science and technology.
COs5: State opinions and express ideas and plans to support specific issues and develop teamwork skills.	Have capacities to manage, adapt, cooperate, and be able to serve as an individual, team member, or leader in teams with multidisciplinary backgrounds.

4.2 Course content formulation

According to the objectives of CDMCU and the type to which it belongs, the teaching contents are reorganized and modularized. Under new instructional planning, the contents of this course are divided into four modules, i.e., settings for development, internal resources, peripherals, and comprehensive design. Comprehensive design integrates most pertinent skills such as technique, problem-solving, and teamwork. Combined with actual work, students are asked to design practical MCU-based products using their learned knowledge. As a result, students are able to adapt to the software and hardware design process of MCU-based application systems from the module and further improve their comprehensive capacity to solve practical problems. The main modules of the course contents are structured as shown in Figure 2.
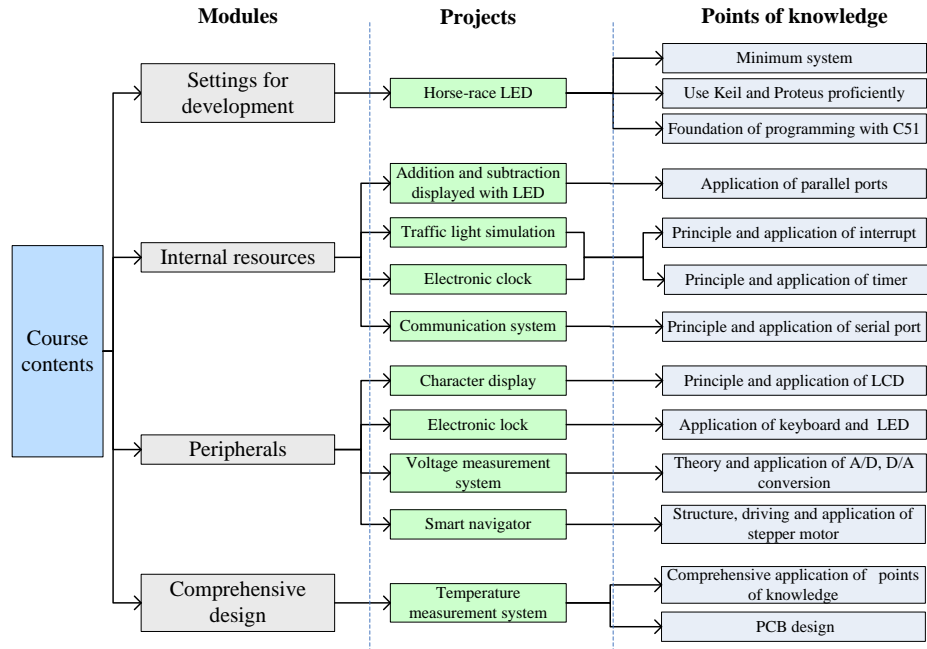
Fig. 2. Diagram of course contents

4.3 Course implementation

The course implementation is split into a theory course and practical training depending on the distinctions drawn from forms of teaching. The theory course uses blended teaching and the practical training uses offline teaching. As seen in Figure 2, each point of knowledge is included in one or more specific projects based on which practical training is carried out, and relevant theories and skills are naturally introduced as well. Conducting practical training in project- or problem-based forms allows students to understand points of knowledge and practice relevant experimental skills, such that methods of instruction can transfer from a teacher-centered model to one based more on students' needs (student-centered). In the specific implementation process, attention should be paid to the following points. First, virtual groups with three to five members could be established to foster participants to have higher levels of team spirit. Assessments will be conducted via group discussion, problem exploration, and the degree of achievement. Second, teachers lead students to identify the problem and extract the corresponding points of knowledge. In doing so, students may review the knowledge they learned when training practical skills. Third, the flip-teaching methodology is included in theory class, in which teachers organize students to form a panel of speakers to discuss related issues with pertinent theoretical knowledge released on mobile devices in advance. Fourth, in the laboratory class, fostering ideas of system

design should be prioritized. Through project training, students should be able to conduct software and hardware design proficiently using Keil and Proteus and solder components onto PCBs.

4.4 Course assessment

In combination with the established course objectives, an evaluation method consisting of formative assessment, comprehensive assessment, and self-perception is formulated. Of these approaches, formative assessment refers to a collection of methods that teachers use to conduct in-process evaluations of student attendance, answer sessions, and classwork, urging students to fully participate in practical classes that turn passive recipients into active learners. Comprehensive evaluation aims to examine students' practical skills and mastery of knowledge through project design and assess if students can flexibly design a desired MCU-based system with the assistance of discussion groups, online resources, or reference cases. Self-perception is carried out in the form of a questionnaire-based survey, the main purpose of which is to obtain the scores that enable students to estimate their own capacities to learn, practice, and solve problems in the process of practice. At the end of a project, the summative evaluation of the CDMCU course can be determined by the weighted sum of adding the scores of the three approaches. The differentiating factor is that we continuously consider self-perception when we try to improve the teaching methodology of the course. The detailed rules for summative evaluation are as follows.

Formative assessment: student attendance×5% + in-class answer session×20% + assignments×5%.

Comprehensive assessment: system plan×10% + circuit design×10% + programing×10% + appearance×5% + achievement of functionalities×10% + innovation×5% + integrality of document×10%.

Self-perception: questionnaire×10% (e.g., Do you think that curriculum design of this form facilitates immersion and practical ability for your learning? All answers are rated from 1 to 5, where 1 = very bad and 5 = very good.)

5 Experimental design and instructional effects

In the medical industry, indicators such as temperature, heart rate, blood pressure, and weight are mandatory for people to check their overall health condition during physical examinations. To obtain these indices in real time, students are asked to design a temperature measurement device where an MCU (e.g. STC89C51) is used as a controller to detect and display the temperature of the target human body (e.g. fingers) in digital format. The device will sound an alarm when the measured temperature is higher or lower than the threshold.

5.1 Requirements and tasks

The requirements for the temperature measurement device are as follows:

1. Measures temperatures from −20 °C to +100 °C;
2. Is accurate to at least 0.5 °C;
3. Has a digital display;
4. Has a settable temperature alarm condition;
5. Sounds an alarm when the measured temperature is outside of programmed limits.

The specific design tasks are as follows:

1. Clarifying the problem and reviewing the literature;
2. Setting out a scheme and providing an overall design;
3. Selecting components and creating a schematic;
4. Programming and verifying the simulation;
5. Creating and testing a PCB;
6. PCB assembly.

A typical case design consists of schematic design, programming, PCB making, and assembly.

5.2   Schematic design

The layout of the schematic of the temperature measurement system is shown in Figure 3, in which basic modules such as minimum system, display, buttons, temperature, and alarm constitute the main body. The minimum system mainly includes the controller/MCU, clock circuit, reset circuit, crystal oscillator, and power. All students are required to master the principles on which the device works. The four-digit, seven-segment common cathode LED (7SEG-MPX4-CC), serves as a display module that displays the collected thermal data in digital form and acts as an interface to set the upper and lower temperature alarm conditions. According to the system requirements, the button module, with three independent buttons, is used to set up the control mode and adjust the alarm thresholds. The buttons, "control mode", "temp up" and "temp down" connect to pins P3.1, P3.2, and P3.3, respectively. Given that no other devices are attached to these three pins, mutual interference can be excluded, and the status of the buttons (pressed or released) can be confirmed directly by logic levels coming from corresponding pins. In this case, many pins remain unoccupied, so students do not need to consider the shared-medium strategy. The digital thermometer adopted in the temperature module, DS18B20, has a small size, low power consumption, anti-jamming characteristics, and high resolution. Information is sent to/from the DS18B20 over a one-wire interface. Thus, only one wire needs to be connected from an MCU to a DS18B20. For the alarm module, a buzzer is used to send out a signal when the measured temperature exceeds the predefined range.
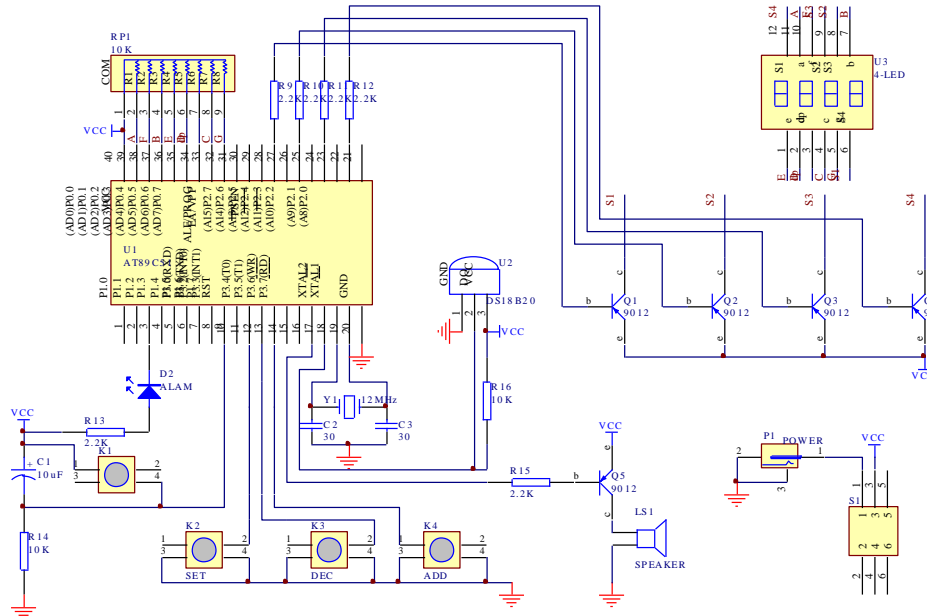
Fig. 3. Schematic of the system

5.3 Programming

In the programming phase, the source code is edited and compiled using C or assembly language under Keil software. The flow chart is shown in Figure 4. The main function starts with the initialization of the 18B20 bus and timer. Then, the predefined temperature range is read. If the pressing of the "control mode" button is detected, the subroutine to run is decided by counting the number of times the button is pressed (1, 2, and 3 for *max-threshold*, *min-threshold*, and *quit*, respectively). Otherwise, if the temperature derived from the thermally sensitive sensor is outside of the range acquired from the flash memory of the temperature trigger, the buzzer will make a noise until the temperature returns back to that range. The subroutines used in this case include temperature reading, display, alarm, delay, and timer interrupt. Last, Proteus software is used to verify the code and simulate the schematic. The layout of the simulation diagram is shown in Figure 5.
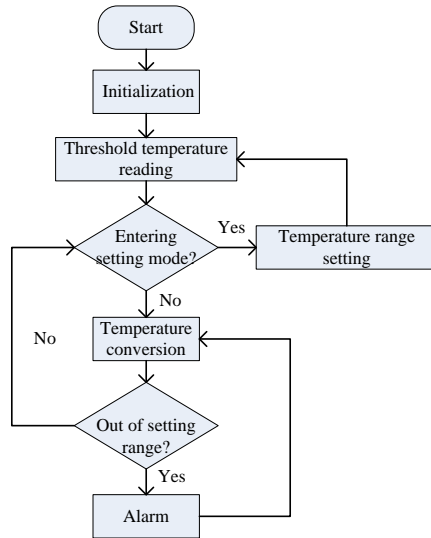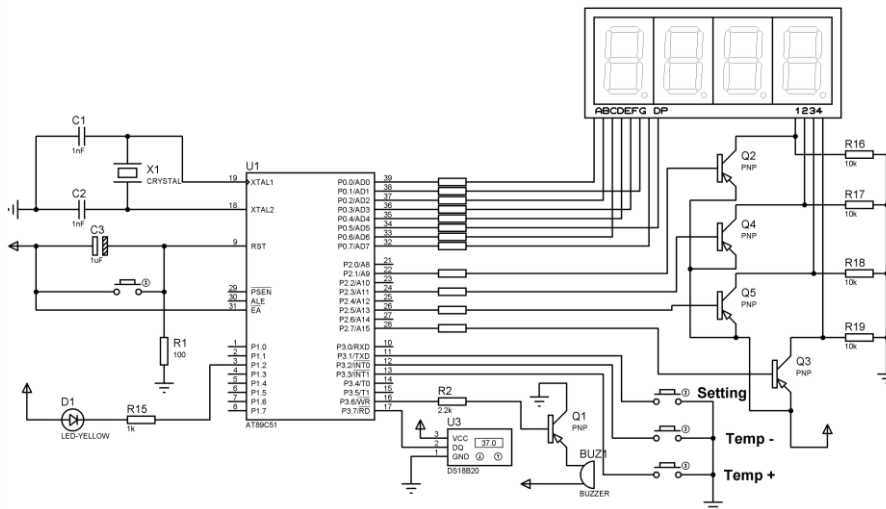
Fig. 4. Procedure flowchart

Fig. 5. System simulation diagram

5.4 PCB making and assembly

Altium Designer software is used to draw the PCB of the system, as shown in Figure 6. The ability to control exactly how one's PCB will behave is vital, so setting up rules and constraints for routing a PCB should not be viewed as a negative part of this project. To prevent manufacturing problems and ensure the electrical performance of the circuit

board, special attention should be paid to components such as trace widths, trace clearances, trace routing, vias, and planes. Figure 7 shows an example of an assembled product being tested, on which the seven-segment LED displays the measured temperature. The current temperature is 28.7 °C, which falls within the predefined range (20–38 °C in this context), so the buzzer remains mute and the LED is unlighted.

Through these steps, students experience the standard procedures of prototyping that involves circuit design, programming, simulation, manufacturing, and assembly, helping them better understand the meaning and importance of integrated design. Such a process also further enhances the integrity and systemicity of the course they took.
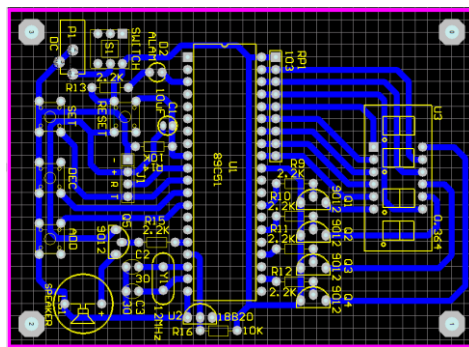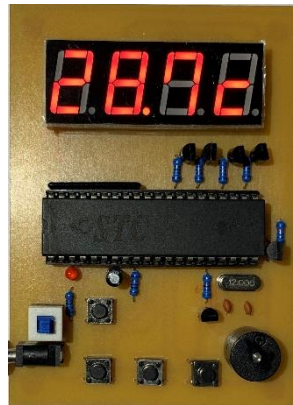

Fig. 6. PCB prototyping

Fig. 7. Example of the final assembled PCB

5.5 Instructional effect

A comparison was conducted, in which the data came from Biomedical Engineering (BME) undergraduate students following the CDMCU course in NSMC before and after the instructional reform. The traditional teaching methodology was implemented on students of grade 2017, while the OBE-based instructional method proposed in this study was implemented on those of grade 2018. Since the curriculum reform was

launched, it has been positively appreciated by students, teachers, and counselors. An analysis was carried out to evaluate the academic performances and questionnaires. The results are shown in Figure 8. The proposed instructional method has advantages over the traditional one in all six criteria. Of these indices, grade 2018 enjoys a 17.39% increase in the "course evaluation" growth rate, making it the fastest-growing index. "Software skill," "proficiency with programming," "learning motivation," "score," and "quality of interactivity" of grade 2018 exceed those of grade 2017 by 9.41%, 12.35%, 11.54%, 9.33%, and 11.11%, respectively.
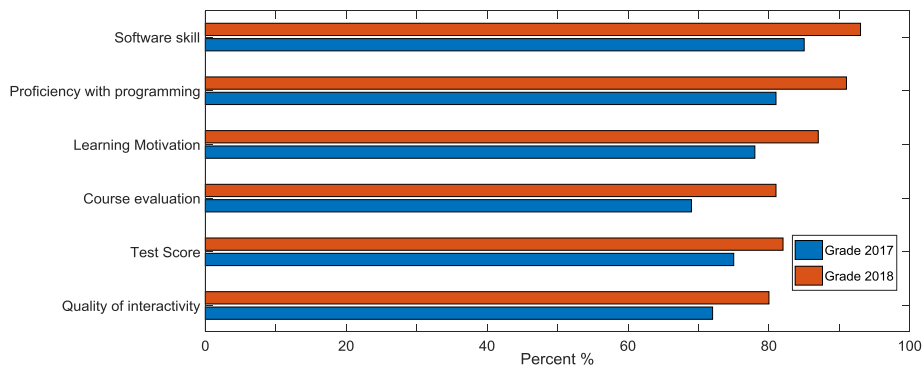

Fig. 8. Comparison of teaching effect before and after the implementation of instructional reform

In the effort to guarantee the implementation of instructional reform on the CDMCU course, students have not only improved their practical skills but have also consolidated relevant theoretical knowledge in the process of practice. As a result, the comprehensive abilities of students to address specific problems were enhanced, laying a solid foundation for students to pursue their careers in the future.

6   Conclusions

The adoption of the OBE-oriented instructional method in the CDMCU course, which focused on the integration of practical ability and instructional objective, suggested an approach to foster students to learn and think creatively. The changes and optimization conducted on the structure of practical teaching inspired students to practice with strong desire and motivation, enhancing effectiveness, flexibility, and scientificity in instructional practice. The following conclusions could be drawn.

1. The OBE-oriented teaching method enables transforming teacher-centered instructional activities into novel student-centered practice. The task of making electronic products plays a critical role in promoting student participation. Learning enthusiasm and practical ability derived from taking the CDMCU course are widely pushed during the process of turning passive learning into active learning. Involving a

straightforward production chain in class is useful for students to obtain a preliminary understanding of the manufacturing process, broaden their minds, and cultivate the capacity to cooperate. Students can also accumulate related operational experiences.

2. Learning outcome evaluation is an important part of the OBE-based pedagogical model, in which teacher assessment coupled with student self-perception together constitute a dual mechanism. Considerable emphasis is placed on the combination of formative and summative assessments, qualitative and quantitative analysis. Evaluations even come from peers and individuals, thereby integrating regularization, diversification, and rationalization.

3. Instructional modules that center on different instructional focuses are reorganized in terms of the distribution of theoretical knowledge. Engaging students as partners in learning software skills motivates them to learn actively, enables them to deeply recognize and apply working principles of MCU, and imparts in them a more perceptual understanding of the overall process of design, manufacturing, and assembly. Integrating all these steps under the context of OBE-based reform provides students with new opportunities and platforms to take advantage of existing experimental conditions and participate in further Programs of Innovation and Entrepreneurship for Undergraduates in the future.

7 Acknowledgement

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