KOSEN's Capstone Project: Fostering Engineers through Software Design and Implementation

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The curriculum at the National Institute of Technology (KOSEN) in Japan is designed to be completed in five years. The KOSEN's curriculum has features that enable students to acquire knowledge and skills at or above the same level as those at university by the time they graduate. In the graduation research project that the authors conduct, we intend to foster students as innovative and practical engineers so that we provide them with the opportunity to set their own goals and learn by overcoming complex tasks that integrate the knowledge of the software field with technical skills and problem-solving skills by themselves under the teacher's qualitative support according to each student's progress. As the number of students accepted in the laboratory each year is small, each student can set their field of interest and theme, and by deciding how to design and implement the program, teachers can provide learning support based on engineering design.

In this report, we will provide the students' project theme, "Development of a wayfinding system using AR in the complex structures of the building," which has been improved and expanded by multiple students over a long period of consecutive years. Through assisting the students of this project, we have observed the students and found how and what the students involved in the project learned from the information they obtained from academic papers and introductory computer language books, how they selected the appropriate technology by themselves, how they developed the practical software system, how they managed the software development life cycle, and how they overcame technical difficulties. Specifically, the students learned to build user interfaces based on augmented reality, route search algorithms, and server-client software system architecture, and those technologies could not have been taught in the class. The students also gained soft skills such as the ability to make proposals and answer questions about how to improve the project, the ability to discuss with their peers and teachers, and the ability to write reports.

Furthermore, the characteristics of this educational program will be discussed based on the observation of each student's actions and attitude to conduct the project from the educator's perspective, and through a questionnaire after the students finish the project.

Keywords: *capstone project, self-directed learning, self-regulated learning, skill-oriented learning, engineering design*

Introduction

Colleges of Technology (KOSEN) in Japan are five-year institutions where students enter after graduating from junior high school at age 15 and learn general and special subjects for 5 years. The National Institute of Technology (NIT) Headquarters, an independent administrative institution in Japan, organizes 51 KOSENs across 55 campuses. Their primary mission is to foster engineers ready to contribute to the workplace in each special engineering field. As with ordinary general high schools, students begin with general education, such as Japanese language, English, social studies, mathematics, and physics in the lower grades. Then, they gradually acquire specialized knowledge and skills related to their departments. KOSENs also offer advanced courses, which provide more than two years of education for students who graduate from the regular courses to acquire a bachelor's degree.

National College of Technology (KOSEN), Toyota College, where the authors belong, is the only KOSEN in Aichi Prefecture, located in Toyota City. Toyota College has five departments, and the authors belong to the Department of Electrical and Electronic Engineering, emphasizing foundational courses such as electrical circuits, electromagnetism, electronics, automatic control engineering, and so on. However, graduates are also expected to obtain skills in developing computer software for microcontrollers, data analysis using a computer, and how to use a computer simulator.

To become engineers, students must acquire essential engineering design skills, including planning, problem investigation, and project scheduling. To support this development, graduation research is offered as a mandatory capstone project in the final academic year. This capstone project serves to confirm the students' mastery of specialized knowledge and skills, comparable to the level expected of a university bachelor's degree graduate. This paper describes the approach taken in the author's laboratory at Toyota KOSEN to foster software design and implementation skills through graduation research following the department of electrical and electronic engineering curriculum.

Pedagogy

Beppu (2011) emphasized the necessity of providing engineering students with a fundamental understanding of the engineering design process and then proposes an integrated curriculum that incorporates design theory and creativity exercises before conducting graduation research over multiple academic years. The author also argued that engineering students must understand the theoretical principles of design and apply them to practical manufacturing processes to study and implement engineering design effectively.

Shurin et al. (2021) surveyed about the benefit of the capstone project against four stakeholders (academia, industry, students, and advisors) and concluded that the capstone project plays a central role in developing engineering students' readiness for industry by fostering the most important and significant skills, such as independent learning, ability to adjust to change, multidisciplinary, and adaptability to the industries.

L.F. CAPRETZ (2024) developed an engineering design course for senior-level students enrolled in the software engineering program and described that students engage in the full design process. The author concluded that the most critical aspects of the student experience was the soft skills, such as recognition of the importance of team efforts and group dynamics, the practice of cooperation and appreciation of different talents, the exposure to the complete cycle of design from concept to final production in the form of prototype, and the integration of economic, legal, and human factors into the design decisions.

Methods

1. Curriculum of the Department

The Department of Electrical and Electronic Engineering offers a curriculum focused on electrical and electronic engineering from the first through the fifth years. Table 1 shows the special subjects provided in this department at Toyota College in 2024. The curriculum comprises several parts: theoretical subjects related to electrical and electronic engineering, mathematics practice, experimental laboratories, Problem-based Learning, Learning, English for engineering, and software subjects.

2. Software Subjects

To graduate from NIT, Toyota College students are also expected to acquire skills in developing computer software for microcontrollers, data analysis using a computer, and utilizing a computer simulator. Therefore, the department offers software subjects such as Microcomputer Engineering in the second year, Basic Programming in the third year, and Programming Techniques in the fourth year.

Table 1. Curriculum of the Special Subjects in the Department

1	2	3	4	5
	Basic English for Electrical Engineering		English for Electrical Engineering	
Mathematics for Electrical Engineering		Practice of Basic Mathematics, Physics, Electrical and Electronic Engineering		
Fundamental Electrical Engineering	Electrical Circuit Theory			Digital Circuit Theory
		Electromagnetism		Power Electronics
			Electronics	Semiconductor Theory
			Electronic Circuit Theory	Automatic Control Engineering
			Energy Transfer	Electrical Power
			Electrical Measurements	
			E.E. Eng Seminar	
Information Literacy	Microcomputer Engineering	Basic Programming	Programming Technique	Software for Electrical Engineering
		PBL for Electrical Engineers		Graduation Research
Electrical Engineering Laboratory				

In the second year, students study discrete mathematics, logic circuits, and embedded microcontroller programming using loops and conditions. The third year focuses on C language syntax, including input/output on a terminal, functions, array variables, input/output through the file system, and pointers. The fourth year curriculum addresses modular programming and introduces data structures and numerical calculation methods for general-purpose applications.

In the third-year PBL, students create a line-tracking robot and design a program to acquire values from a light-detecting sensor and change the speed of toy motors. In the fourth year PBL, students create soccer robots using LEGO Mindstorms EV3 and design programs to compete with the robots their classmates created.

Additional subject, Software for Electrical Engineering, is conducted in the fifth year, though programming language education is limited to Microcomputer Engineering, Basic Programming, and Programming Technique.

3. Pre-research Activities

In the second semester of the fourth year, students are assigned to laboratories through a course called Electrical and Electronic Engineering Seminar as a pre-research. Each laboratory conducts about four seminar sessions for the students, and the students can prepare for fifth-year research activities. One of the authors' laboratories develops software applications for various purposes using advanced techniques that students don't learn from the curriculum the department provides, so it provides short lectures and practical exercises about the topics below.

- Fundamentals of object-oriented programming in C++
- Event-driven programming
- Collaborative application development in a team

Object-oriented programming and event-driven programming are not included in the department curriculum. However, they are practical and fundamental techniques for developing the practical software products described later in this paper. Therefore, the author introduces concepts such as classes and inheritance in the pre-seminar, which are not available in C and are common in modern languages but difficult to self-learn.

In the department curriculum, in programming classes, each student creates the same program by himself/herself on the assignments. However, engineers work as a team in the practical workplace to develop software products. So, the purpose of collaborative application development in a team is to provide students with experience in developing software. At the same time, they communicate with their teammates, share the problems that they face, and confirm their solutions.

4. Graduation Research as a Capstone Project

As a capstone project, all KOSENs conduct graduation research for the fifth-year students based on what they have learned so far, deepening their understanding under faculty supervision while learning to manage research projects independently and continuously. Students conduct graduation research for three hours a day, twice a week, for nine months in the authors' department. They also learn how to write a research thesis and give a presentation in class. In addition, advanced course students engage in further research during Special Research I and II in their first and second years.

Fifth-year regular course students are typically 20 years old. Advanced course students are 21 to 22 years old, corresponding to second and fourth year university students. Each laboratory accepts 3 to 6 students. Each faculty member in the department provides research guidance for the students, which varies by special field.

Both graduation and special research involve mid-year poster sessions and final oral presentations. Students also must submit a graduation thesis (or a completion thesis for Advanced Course second-year students).

5. Laboratory Operation

One of the authors' laboratories conducts software-based research on educational support and image processing using webcams. Figure 1 shows students studying in the laboratory.

The laboratory's policy is “independent problem-solving and project management skills.” Based on this policy, the laboratory requires the students to improve their independent problem-solving and project management skills. Students are expected to define research themes, plan systems, and identify necessary knowledge independently, wherever possible.

Figure 1. Students studying in the laboratory

Students can choose previous projects to update or propose new ideas and finalize topics through discussion with faculty. Innovation is not strictly required in graduation research, and students are encouraged to pursue interesting topics personally and engage in the engineering design process by themselves. In the laboratory, we hold one-on-one progress reports and discussions on direction approximately once a month.

The past projects conducted in the laboratory are as follows.

- Development of a 3D scanning system using a webcam
- Exercise form evaluation and improvement using pose estimation
- Fashion coordination recommendation using machine learning

6. Laboratory Projects

One long-term laboratory project involves developing an indoor way guidance system. This project was initiated in 2012. Visitors often get lost when assuming guidance within buildings with complex structures and layouts. To address this, students created a system where users set destinations on smartphones and scan markers placed at intersections. AR techniques overlay arrows on the screen to guide users.

Students proposed the system, and its design and architecture were decided through discussions with the laboratory professor. Initially, the server handled arrow rendering and pathfinding, while the client displayed results. Students independently researched pathfinding algorithms like Dijkstra’s method.

In subsequent years, students improved the system by addressing issues and incorporating new features made possible by smartphone performance improvements. Improvements included UI, server-client structure, libraries used, and system operation, which are not taught in the department curriculum. Figures 2 and 3 show the students' proposed and updated architecture and interface.

7. Skills Acquired

Although the department curriculum emphasizes C programming, various other languages are used in the laboratory depending on the project, such as JavaScript for browser interfaces and Python for data processing and machine learning. Typical libraries, such as Three.js for 3D graphics and AR.js for augmented reality, are also used. Due to frequent library updates, online resources are commonly used.

As each project uses different tools, students are expected to learn them independently rather than in organized lectures conducted during the four-year seminar.

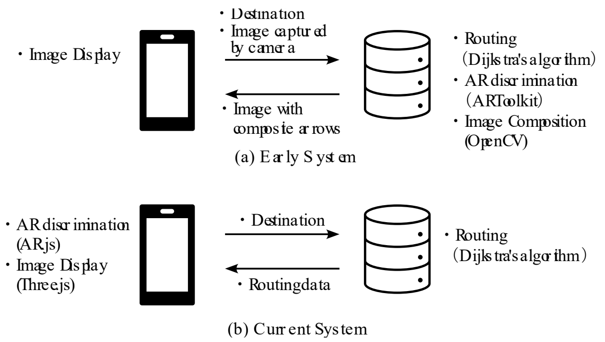

Figure 2. System Structure Diagram of the Student's Capstone Project of the Way Guidance System

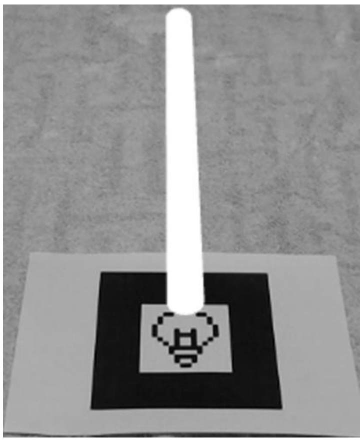

Figure 3. Example of the Screen of the Way Guidance System

8. Role of Faculty

Faculty conduct meetings with students once or twice a month when requested to review progress and provide guidance. In addition to checking progress, faculty members use this meeting to confirm that there are no research problems, and to check for necessary equipment, software, books.

Students independently select learning resources, request book orders, and share information, autonomously fostering a collaborative laboratory environment.

In some cases, students change the software components already implemented by former laboratory members due to limitations in solving the development problems. For instance, in 2023, a student switched from A-Frame to Three.js after finding the former insufficient. Faculty members support specification planning, but implementation is the students' responsibility.

Results and Discussion

At the end of the academic year 2024, an anonymous questionnaire titled "Survey on Independent Implementation of Graduation and Special Research" was conducted to assess whether the laboratory provides students with a self-directed, self-oriented, and self-regulated learning environment. The survey targets are small in this report, though four laboratory members—one second-year advanced course student and three fifth-year regular course students—answered. The questionnaire was administered on March 17 and completed by March 18, 2025, using Microsoft Forms.

The questions assessed students' perceptions of the laboratory's policy of "independent problem solving and project management skills." The survey questions include the following.

Q1. Were you able to schedule and meet goals independently?
Q2. How often did you engage in productive discussions with your supervisor?
Q3. Did you feel these discussions were conducted on equal footing between the supervisor and student?
Q4. Was your supervisor available to consult when you needed?
Q5. If yes to 4, was the advice helpful?
Q6. Did you improve your ability to make decisions independently?
Q7. Did you become more proactive in self-learning skills for computer programming?
Q8. Did the collaborative laboratory environment support your personal growth?

Table 2 shows the questionnaire results. The responses were anonymous, and the order of respondents does not reflect their academic year or other factors.

The results were generally positive. All respondents answered that discussions were equal (Q3), and Q6 responses showed improvement in independent decision-making.

Table 2. The Results of the Questionnaire

#	A	B	C	D
Q1	Somewhat agree	Agree	Somewhat disagree	Somewhat agree
Q2	Once per month	Once per month	Once per month	twice per month
Q3	Agree	Agree	Agree	Agree
Q4	Yes	Yes	Yes	Yes
Q5	Somewhat agree	Somewhat agree	Somewhat agree	Somewhat agree
Q6	Agree	Agree	Agree	Agree
Q7	Somewhat agree	Agree	Somewhat agree	Somewhat agree
Q8	Somewhat disagree	Agree	Somewhat agree	Somewhat agree

Students were also asked: "If future students take on the same topic, what should be improved to enhance learning?" Responses are shown below.

- More frequent progress checks would help.
- While AR navigation systems exist, documentation is limited. Early AR programming instruction would be helpful.
- Opportunities for system testing in the real world should be arranged (students cannot organize it alone).
- Guidance on searching academic resources would be beneficial.

These responses clarified that some students needed faculty to provide explanations and assistance related to their research at the beginning. At the start point of the graduation research, considering the wide range of computer programming skills among students, some students likely felt some stress in conducting their research independently. The authors recognize that these issues are future challenges to be addressed for fostering students through a capstone project to have students address self-directed and skill-oriented learning. The survey by questionnaire is something we started this year, and we plan to take similar surveys in the future to provide material for improvement regarding the management of the laboratory.

Conclusions

This paper describes how the authors organized and conducted the software development laboratory in the Department of Electrical and Electronic Engineering at a National College of Technology (KOSEN), in Japan. The laboratory's policy is "independent problem-solving and project management skills." Based on this policy, the laboratory requires the students to improve their independent problem-solving and project management skills. It also introduces a long-term project, and students take initiative in learning and decision-making based on the self-directed/self-oriented/self-regulated learning pedagogical methods. A survey confirms that the laboratory environment supports autonomous research development. However, the authors recognize challenges that must be addressed for fostering students through a capstone project to have students address self-directed and skill-oriented learning.

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