Cooperative Education of Systems Engineering and Embedded System

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Abstract. College of Systems Engineering, Shibaura Institute of Technology has been conducting systems engineering educations to all undergraduate students in the college for seventeen years. Engineers with system architecture design and project management abilities are required in the field of embedded system development. In universities, however, educations are mainly focused on computer science and programming; systems engineering and project management education have been disregarded. We implemented educational curriculum of Systems Engineering and Project Management in Embedded System for graduate program. In this paper the course design, execution and evaluation are described.

Introduction

Education of systems engineers, who have high level technological knowledge and skill in their major filed as well as can plan, design, and manage interdisciplinary systems, are required. College of Systems Engineering, Shibaura Institute of Technology was founded in 1991 and has object to educate systems engineers by delivering major subjects and systems engineering as minor subjects concurrently.

Three stages of systems engineering students are defined: First stage students have fundamental knowledge and skill of their major fields and systems engineering. Second stage students are capable of executing systems engineering in their specific technical fields. Third stage students/engineers can plan, design, and manage interdisciplinary systems. In undergraduate education, the first stage education is completed in the Institute.

The proposed master course curriculum in graduate school aims at educating the second stage students in the field of embedded systems. In this research, cooperative education of systems engineering and embedded system is devised, executed, and evaluated.

Proposed course consists of two parts: In first part we discuss analyzing, planning, developing of embedded networked systems with case studies as well as deliver fundamental technologies. In second part, students have Project Based Learning (PBL) of project planning and architecture designing of embedded system.

In this paper, at first we show general systems engineering curriculum for undergraduate students and education road map with the proposed course. Secondly, embedded networked system is introduced and defined in the curriculum. In third part, requirements for educational curriculum of systems engineering and project management is defined in the field of embedded system. The curriculum structure and contents are design to satisfy the requirements. In forth part the course

executed in 2007 is evaluated and discussed.

Systems engineering curriculum for engineering students

Systems engineering undergraduate curriculum. College of Systems Engineering, Shibaura Institute of Technology was established as an educational research organization of science and technology with systems engineering in a common base in 1991. The College is composed of 5 departments (figure 1) which have individual major subjects and share common Systems Engineering and Information Technologies curriculum. Students study a major course and systems engineering as a minor to become an engineer with high level technology in each field and systems engineering back ground.

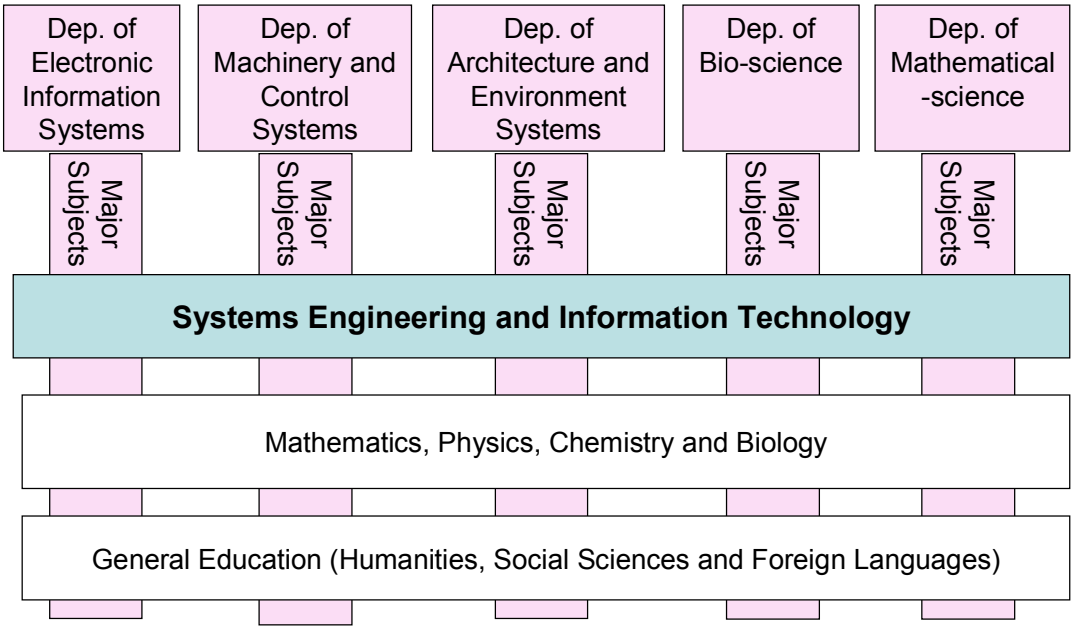


Figure 1 Departments and curriculum in the College of Systems Engineering

As systems engineering education for undergraduate student, we have executed joint curriculum systems engineering (INCOSE 2007) (Sage) and project management (PMI 2004) as shown in figure 2. Three lectures of system planning, mathematical programming, and project management, and three exercises are executed in 2nd and 3rd year. In College of Systems Engineering, Shibaura Institute of Technology, about half of the reference curriculum (Jain 2007) for graduate program in systems engineering is delivered as a minor in undergraduate program.

Experiences of project execution are necessary for understanding systems engineering and project management. The challenge is how to teach systems engineering and project management to students who have scarce project experience. In the education, giving the experience including a real experience and a pseudo-experience will be indispensable. Appropriate adjustment of the order of lectures and exercises helps the student's understanding. Moreover, mathematics of probability statistics and the theory of the optimization technique are necessary as prior education of systems engineering and project management. Evolutional Project-based learning of systems engineering and project management (Inoue 2008) is introduced (figure 3). Lectures and exercises

(project-based learning) are staggered and executed alternately.

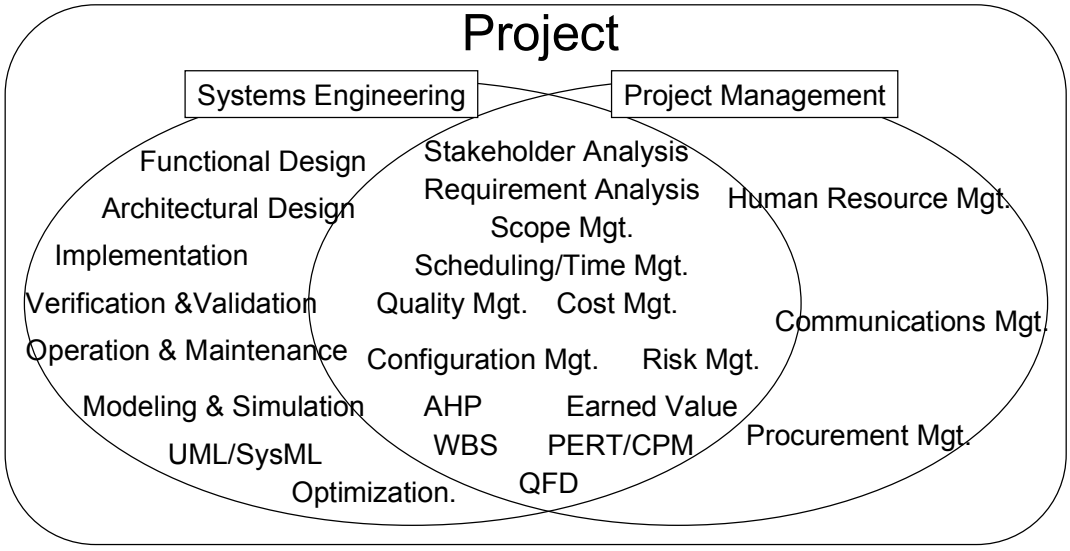


Figure 2 Undergraduate Education of Systems Engineering

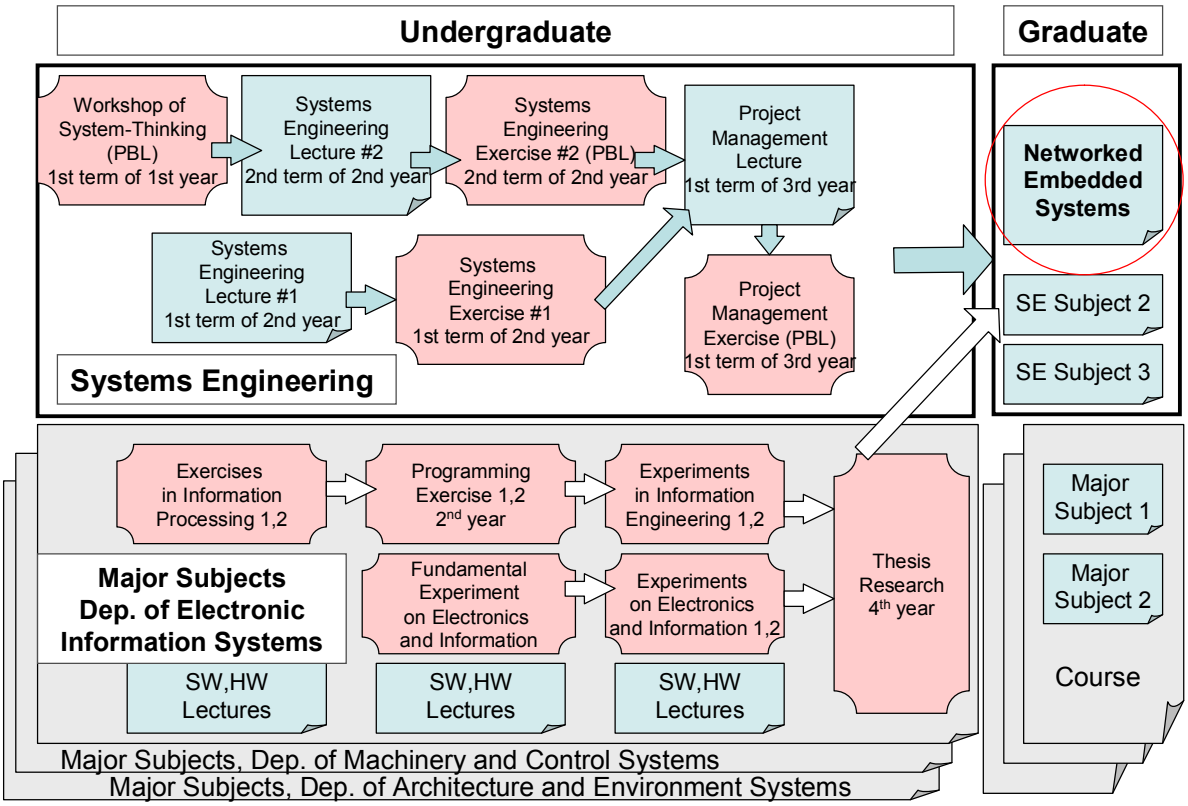


Figure 3 Road map of systems engineering curriculum and major courses

Road map of systems engineering curriculum and major courses. Figure 3 shows road map of systems engineering curriculum and major courses. Systems engineering curriculum is placed

properly with major subjects in each department. However students tend to understand each subject isolated. For most students, thesis researches are the first experience to execute systems engineering in major field.
The proposed cooperative education, networked embedded systems, is placed at 1st year of Master Program just after thesis research of undergraduate program. The purpose of the cooperative education is improving knowledge and experience of systems engineering in major field.

Embedded system and network

Embedded system is a computer system which is embedded in machinery to control it. Embedded systems encompass a wide range of applications, technologies, and disciplines, necessitating a broad approach to education (Koopman 2005). Embedded application areas include: cell phone, automobile, train, airplane, TV, household appliance, camera, printer, robotics, and industrial equipment. Embedded systems have constrains of cost, limited hardware recourses, high reliability, and real-time execution.
Development of embedded system is a multidisciplinary systems engineering and requires participation of wide variety of discipline engineers, which include not only electronics and software but also mechanical engineering, chemistry and architecture. Systems engineering and project management take a vital role in developing embedded system as multidisciplinary system.
In these days, most embedded systems are networked. In automobile 10 to 100 Electronic Control Units are embedded and networked. In building, facilities are hierarchically networked embedded systems as shown in figure 4.

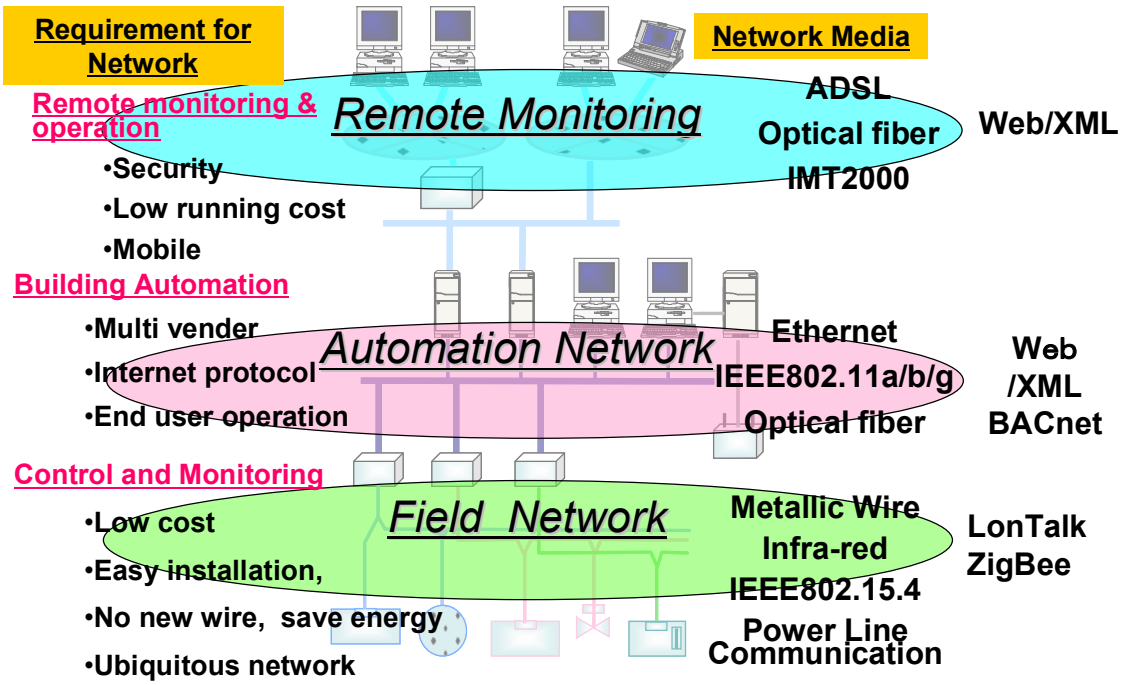


Figure 4 Embedded networked system（Building system）

Cooperative education of systems engineering and embedded system

Goal of course

The goal of the course is to improve students' system engineering capability in embedded system, give them experience of multidisciplinary problem solving, and let them know relation between systems engineering process and project management process.
Students will know technologies and designing of embedded system, and experience project planning. Here, technologies are not only individual network and embedded system technologies but problem solving abilities. Students are required to know what and why to solve problems in real world.

Course design

Figure 5 describes course design for Networked Embedded System at graduate school. Lectures and exercise on embedded system and network are placed in first half, and exercises on project planning and architecture design of networked embedded system are placed in second half.

Network	1. Introduction to networked embedded system 2. Case study: Development of networked embedded system in industry 3. Home network and ubiquitous network (network media and protocol) 4. Modeling of network system and building management system 5. Real-time / dependable network and car area network 6. Manufacturing system and embedded network
Systems Engineering	7. Systems engineering exercise #1 (Orientation and theme selection) 8. Systems engineering exercise #2 (Requirement analysis and technology survey) 9. Intermediate Presentation 10. Systems engineering life cycle and system architecture design 11. Product line engineering 12. Project management 13. Systems engineering exercise #3 (Project Planning) 14. Systems engineering exercise #4 (Architecture design) 15. Final presentation

Figure 5 Syllabus for systems engineering in networked embedded system

Embedded system and network

The first half of course consists of follows:
Introduction to networked embedded system. At beginning of course, surveys are carried out to grasp each student's prior knowledge and requirement for embedded system, project management, network, and systems engineering to give students proper introduction and

adjustment of course. After that, technical and systems engineering characteristics of embedded system are described.

Case study： Development of networked embedded system. Case study shows how to analyze issue and requirement, plan and initiate a project, and design system in real system development. Students are beforehand provided with a case book based in real development (Honda1993). In the class students discuss the case and are motivated to study the course.

Home network. Designing home network is a good educational material to analyze diverse needs and resource restrictions for embedded system. Home network standards (ECHONET2005) (IEEE2003) (ZigBeeAlliance2003) and implementations are lectured and their systems engineering are discussed.

Modelling of network system and building management system.
System modelling and system architecture designing are lectured with building management system which requires divers disciplines such as mechanical, electrical, and information engineering, and architecture. Different countries have different business architectures which influence system architecture and technical standards (ANSI/ASHRAE 2004）(LonMark 2000). The lecture shows that society and business practices affect technology and system architecture.

Real-time / dependable network and car area network. Dependable and real-time embedded system is lectured with examples in automobile applications. Ten to 100 ECU (Electronic Control Units) are embedded and interconnected with network in an automobile. Requirements for electronics and distributed system in automobile as well as design policy and standards (FlexRay Consortium) are discussed here.

Manufacturing system and embedded network. Hierarchical architecture of distributed embedded system is lectured with example of manufacturing system application. Layered networked system (CC-LINK) from machining, assembling, quality control, process control to factory management is discussed with system architecture designing.

Systems engineering management

Lectures on systems engineering and project management are placed in second half of course.

Systems engineering lifecycle and system architecture design. Networked embedded system consists of plural network nodes as described in figure 6; each node is constituted of electric/electronic circuits, software, and mechanism. In development, whole networked system is designed at first. Secondly each networked node, constituting system, are designed and finally each node are breakdown to electric/electronic circuits, software, and mechanisms.

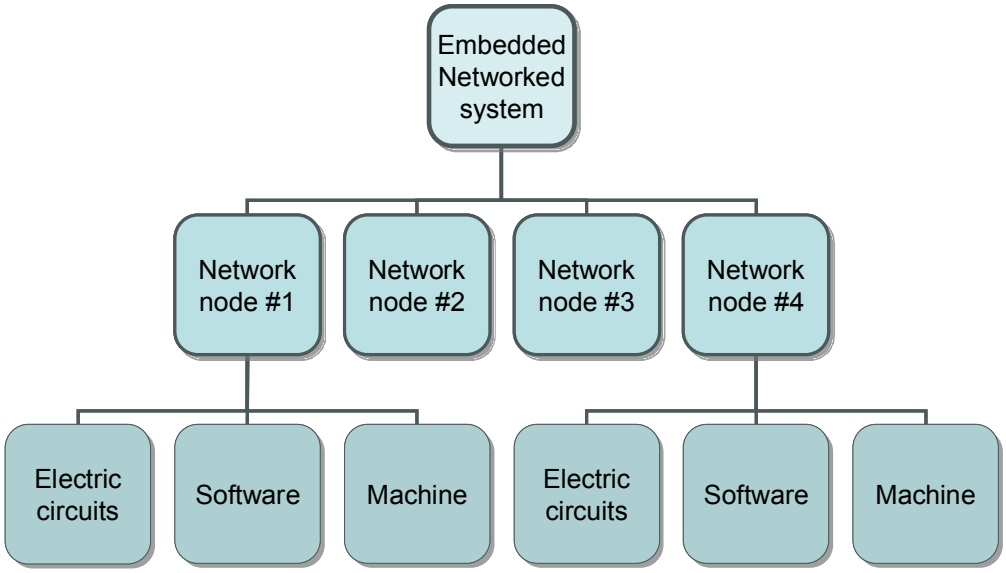


Figure 6 Hierarchical structure of embedded networked system

In this course, whole systems engineering process is combined with two process model. Higher level system engineering process, where whole system requirement is defined, system is divided into nodes, and nodes are implemented, integrated, verified, and validated, is based in the systems engineering process model proposed by INCOSE (INCOSE2007). Lower level systems engineering process, where requirement for each node is defined, and node is divided into software and hardware, is based in embedded software process model proposed by Information-Technology Promotion Agency, Japan (IPA/SEC2007).
System architecture design, where the relations and interfaces among constituting components are defined, is one of the most significant processes for embedded system which is constructed with multi-disciplines. Education of system architecting, however, is very difficult. In the course, after systems engineering process is delivered, cases of system architecture design are discussed and exercises on architecting are executed.

Productline engineering. Software productline, where embedded systems share software architecture and software components, improves quality and reduces cost and time of development. Product line engineering is constructed on technologies, organizations, and project management. The course is mainly discussion on introductory papers for software productline to show students importance of productline.

Project Management. Lecture of project management is placed in the third year of the undergraduate as option, and some students have studied basic project management knowledge. However, for students with some knowledge of project management, it is very hard to own projects and execute projects properly.
In the course, the exercise of project initiating and planning, project management process with proper templates is delivered to students.

Exercise theme

Proper exercises are indispensable to learn systems engineering management. Exercise themes for project planning and system design on embedded system are prepared for students:

Theme #1. Development of energy management system for air-conditioning and lighting in university campus.

Requirement analysis, planning, and designing of Networked management system for saving energy of existing air conditioning and lighting facilities.

Theme #2. Development of automated class room system.

Requirement analysis, planning, and designing of networked system for controlling video projector, video switcher, lecture recording video cameras, screen, and lighting for class room.

Theme #3. Development of embedded network system for life supporting home robots

Planning and design of components such as sensors, actuators, and contol units embedded in life supporting home robots, and network system interconnecting the components.

Theme #4. Development of interconnecting among heterogeneous home networks.

Planning and designing of interconnecting of different networks for different applications.

Theme #5. (Free theme) Theme shall be selected in area of networked embedded system.

Exercise process

Exercise is executed as following process:

Requirement analysis and technology survey. Define system requirements and survey technologies for planning.

Intermediate presentation. Students present the selected theme, system requirements, and result of technology survey required to the system

Project initiating and planning. Students develop project charter, project scope plan, and WBS (Work Breakdown Structure) for the project. After students have peer review on the plan, faculty joins the review meeting.

System architecture design. Students define functional configuration and physical components. They allocate functions to physical components, define interface and document design. After students have peer review on the plan, faculty joins the review meeting.

Updating project plan based on system architecture. After system architecture design, project plan is updated; scope plan, WBS (PMI 2006) (Hagan 2002) are expected to be improved.

Final presentation. Students have a presentation of project plan and system design documentation.

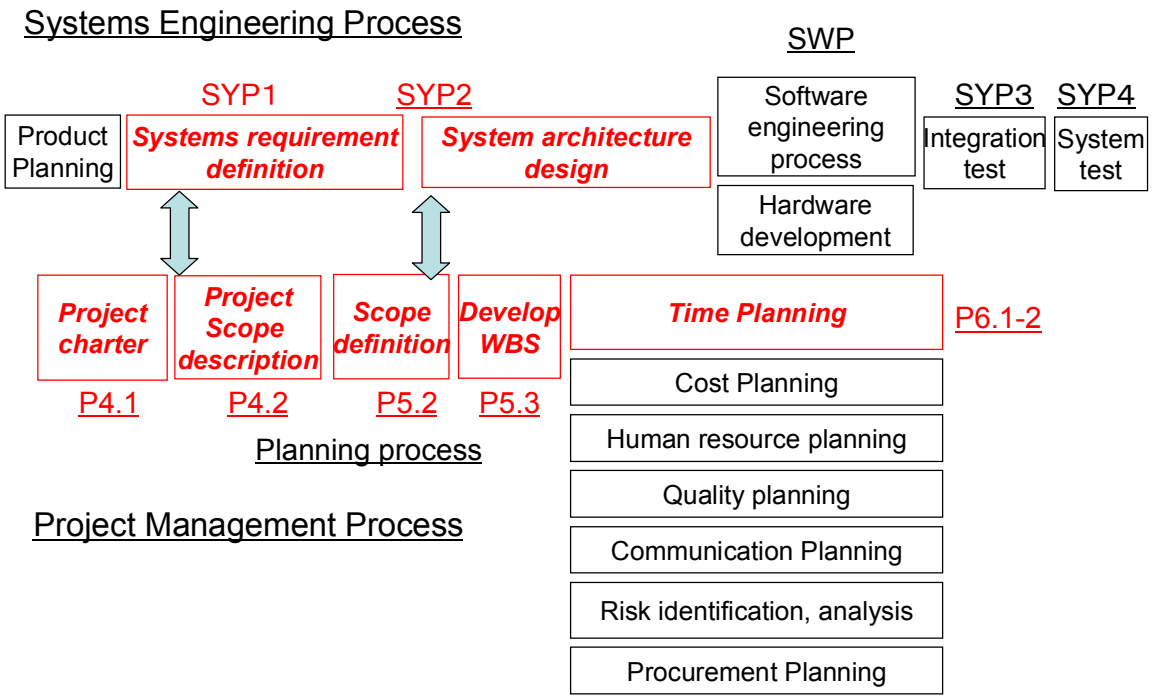


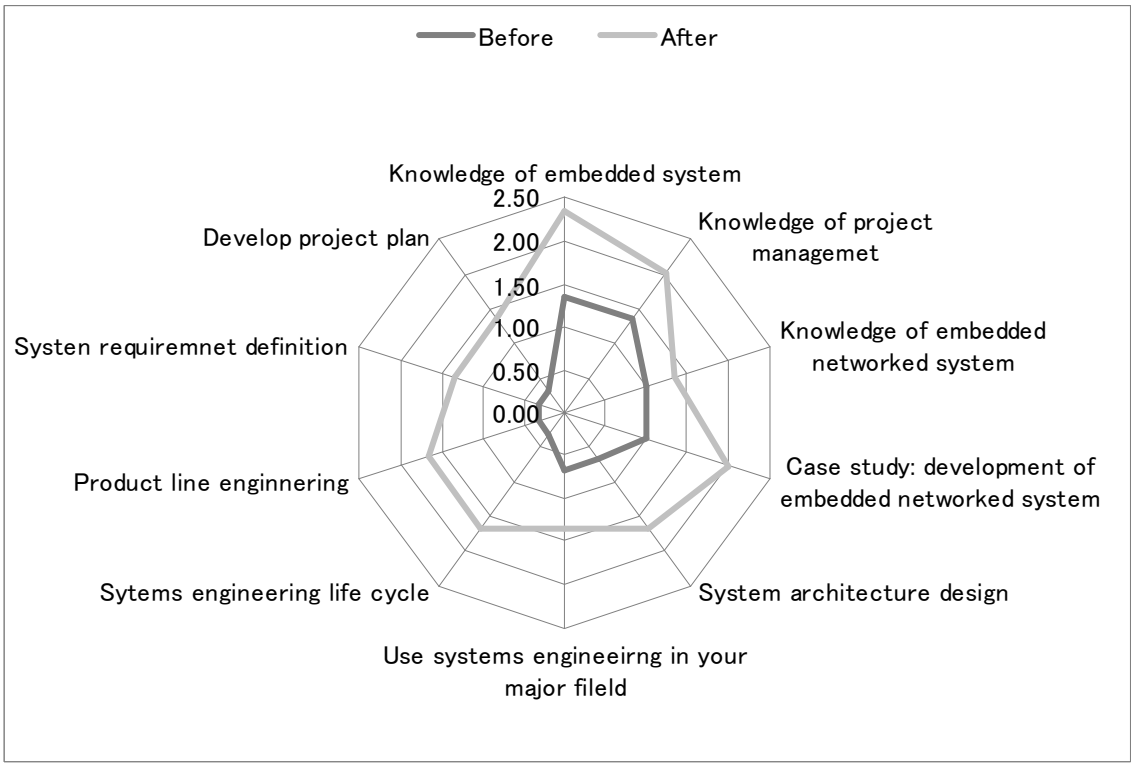
Figure 7 Systems engineering process and project management process in exercise

Systems engineering and project management process for the exercise are shown in figure 7. In the exercise systems engineering process (IPA/SEC 2007) and project management process (PMI 2004) are associated to guide students to execute exercise.
Scope plan is documented twice. The original scope plan is documented just after system requirement is defined. The scope plan is revised after architecture design is finished. The purpose of revising plan for students is experiencing change at scope plan, especially WBS, after designing system architecture.

Execution and evaluation of class

The course is executed and evaluated. The evaluation is based on advancement of students, questionnaires, and interviews of students.

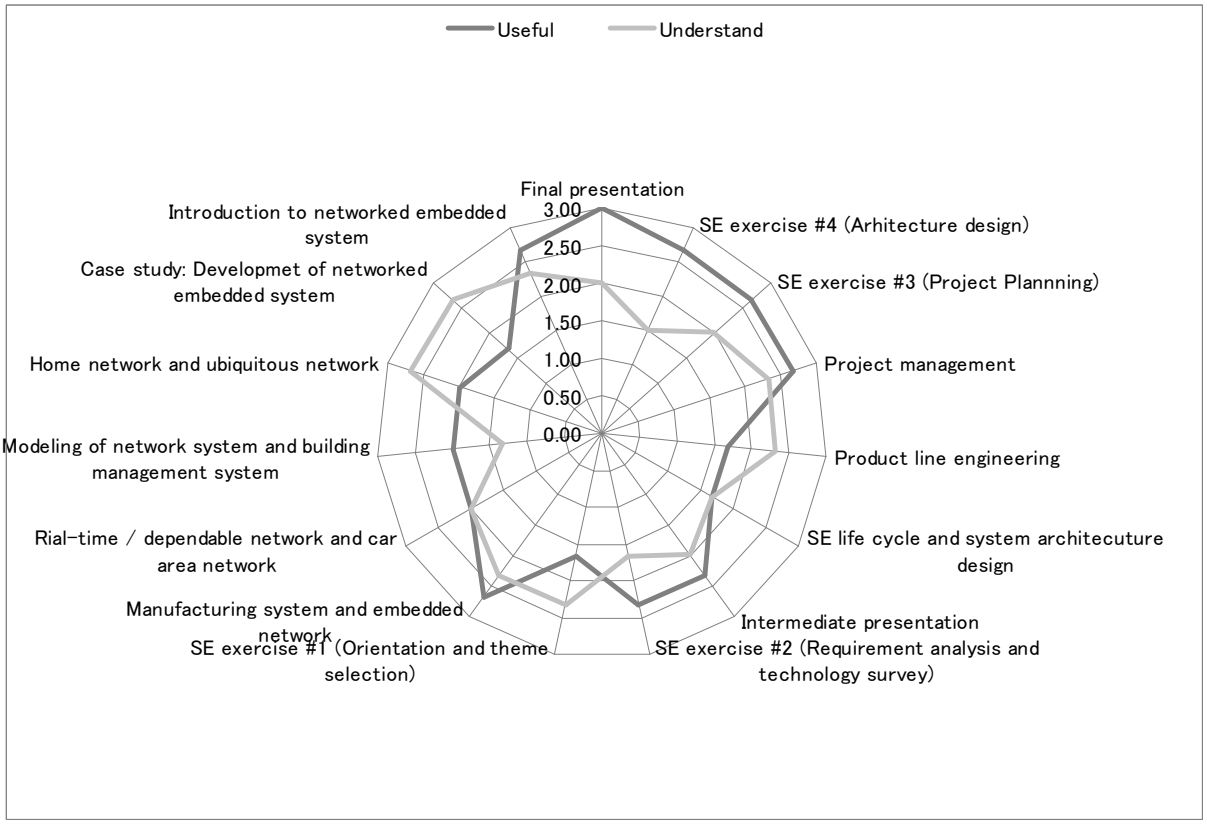
Variance of knowledge and skill between before and after classes. Figure 7 shows that before taking class, knowledge of embedded system, network system, and project management are higher, in the other hand, capabilities of project planning, system requirement definition, systems engineering life cycle, architecture design, and product line engineering are lower. After class, these capabilities were improved.



3:High, 2:Intermediate, 1:Low, 0:No

Figure 8 Variance of knowledge and skill between before and after classes

Level of understanding and usefulness from student's view. Though students tend to consider what they can easily understand useful, and what they find difficult useless, this class is not the case as indicated in figure 9. Students consider exercise of systems engineering management more useful than technical knowledge, though they can easily understand the latter than the former.



3：Fully understand（Most useful），2：Mostly understand（Useful），1：Little understand（Less useful），0: Not understand（Not useful）

Figure 9　Level of understanding and usefulness from student's view

Feedbacks from students. Students reactions are "In the exercise I experienced requirement analysis and architecture design for the first time. I took deeper knowledge of embedded system", and "Exercise was rather hard, but class was interesting. Project management and system architectecting will be useful in my future carrier". Though students had a hard work for the systems engineering exercise, they understood the importance of systems engineering, architecting, and project management.

Discussion

Results of course are discussed and evaluated here. What was attained and further issues are described.

Course layout (Lectures of embedded system and network are placed in the first half term, and lectures and an exercise of systems engineering management are assigned to the second half term.) Allocations of lecture and exercise seem appropriate, because the lectures of embedded system in the first half term dealt with not only individual technologies but systems engineering case studies

which gave proper introduction with templates to the exercise in the second half of term. In the other hand, the initial knowledge of students on network and software modelling are widely spread; lecture on network was obliged to start with introductory level.

Skill and experience to utilize systems engineering in specific engineering field.

Students experience planning, systems designing process in embedded system. Their basic modeling skill to document requirement and specification, however, is not enough, because not all students have learned modeling language such as UML in their undergraduate. In graduate school, fundamental education of modeling language SysML (OMG 2007) for systems engineering, is indispensable.

Relation between systems engineering process and project management process.

In exercise the first scope plan and WBS (Work Breakdown Structure) was documented just after system requirement is defined. The second WBS revised after architecture design was added with WBS elements based on project deliverables.

However, if the first WBS was constructed by phase decomposition (PMI 2004) (Haugan2002), the revised WBS, even after system architecting, tended to be more phase decomposition than deliverable decomposition. The way of decomposition tends to be fixed at first documenting WBS.

Conclusion

Cooperative education of embedded system and system engineering was designed and executed for the master program of graduate school. Since lecture on embedded system and exercise of systems engineering were closely associated, students were motivated to understand development of system. Cooperative education of individual technologies and systems engineering is useful for students.

Students consider exercise of systems engineering and project management is the most important in the course. The exercise, however, was difficult for some students; modelling education and some guided process are preferable to facilitate system engineering exercise.

As a whole graduate program, we will enhance system design education with system modelling language and architecture description language, and project based learning from requirement to implementation, verification, validation with project management.

Systems Engineers, who lead systems engineering in each engineering field and chalenge inter-disciplinary system planning and design, are reqired. These cooperative educations of individual technology and systems engineering is effective for most engineering fields.

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