A Study of Teaching and Learning Model Development for Engineering Education

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Abstract

The purpose of this study is to develop a teaching and learning model for the field of engineering to nurture innovative thinking and competency in engineering elites of the next generation. We have reviewed the literature to find out the necessary thinking and capabilities required for the next-generation engineers, and analyzing domestic and international case studies. As a result, we have created Scientific Inquiry and Creative Activity with Technology (SICAT) as a teaching and learning model applicable for the Fusion Materials field. SICAT model is classified ARDA, CoCD, ReSh type to apply directly in class according to teaching and learning objective. And we developed SICAT teaching and learning model guidebook for teachers. In near future, It should be consolidated the validity of the model and improved succeedingly in engineering education through applying and analyzing effectiveness in classes.

Keywords: engineering education, teaching and learning model, model development

요 약

본 연구는 차세대 공학인재의 사고의 역량을 개발하기 위한 교수학습 모델을 개발하는 것을 목적으로 한다. 차세대 공학인재가 필요로 하는 사고와 역량을 도출하기 위해 문헌을 검토하고 국내외 사례를 분석하였다. 공학 교육, 특히 핵심소재 분야에서 적용할 수 있는 개념적 교수학습 모델로 테크놀로지의 지원을 통한 과학적 탐구와 창조적 활동을 강조한 SICAT(Scientific Inquiry and Creative Activity with Technology) 모델을 개발하였다. SICAT 모델은 교수 학습 목표에 따라 수업에 바로 적용할 수 있도록 ARDA, CoCD, ReSh 유형으로 구분하였다. 또한, SICAT 교수 학습 모델에 대한 교수자를 위한 가이드북을 개발, 제공하였다. 앞으로, 개발된 모델의 교실 현장 적용과 효과성 분석을 통해 모델의 타당성을 공고히 하고 지속적으로 공학교육을 개선해 나가야 할 것이다.

주제어: 공학 교육, 교수 학습 모델, 모델 개발

Ⅰ. Introduction

In a twenty-first century, knowledge-based society, engineers need diverse capabilities such as creative thinking, collaborative skills, leadership, and communication skills in addition to their professional knowledge. Engineers have led not only the IT revolution but also various changes and developments in society. Engineering Education, which educates and trains engineers who are a major workforce for social evolution, should be a core institution of the society (Kim, et al, 2006). In this view, engineering education should predict and accept social changes, and direct itself toward nurturing the next-generation of engineering students who can understand and adopt the changes of society, and create new changes.

Therefore, engineering education should overcome traditional educational methodology that has emphasized students' acquisition and memorization of their field's knowledge. New education methods are needed for enhancing their competency to integrate and reflect on the knowledge of various

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fields in addition to the engineering field, as well as cultivating broader knowledge about core disciplines such as mathematics and sciences, to understand the development of cutting-edge technology.

To meet the needs of the times and to build fundamental foundations that are able to foster next-generation engineers, we need to develop an innovative teaching and learning model for colleges of engineering applicable to actual engineering education fields.

This study is to identify Next-Generation Engineer Students' thinking and competency and to develop a teaching-learning model. Research questions guided this study:

What thinking and competencies are needed of next-generation engineer?

What are teaching-leaning model and instructional strategies for engineering students?

This study's target focused on the Fusions Material field at Hanyang University. This field includes cutting-edge technology departments that combine various disciplinary areas such as material science, chemical, textile, and bioengineering. We explored domestic and foreign cases more focused in the Fusion Material field as well as general engineering education. We identified thinking and competencies needs in this field. Also, we developed teaching-learning model and instructional strategies to apply directly their class.

Finally, three professors and two researchers, as subject matter experts, participated in two focus group workshops and confirmed our model's verification.

Ⅱ. Theoretical Background

1. Literature Review of Foreign Cases

To explore foreign cases of engineering education, we prepared an analysis frame and selected ten universities' cases as follows (Table 1). We searched using the keyword, 'PBL, capstone design, material engineering, chemical engineering, inquiry, assessment, etc.' Therefore, we categorized engineering education model as overall picture, instructional methods and strategies, learner assessment and evaluation, technology supporting learning environment (Kwon, et. al, 2008).

A. Educational Model

The CDIO model made at MIT is a world-wide engineering education model being used in European, Asian, and Pacific countries as well as America. CDIO is based on the concepts of

<Table 1> Universities selected for analyzing foreign cases
<표 1> 해외 대학 사례 분석

Area	University	Main contents
The United States of America	MIT	CDIO model Educational reform through the technology
	Virginia Polytechnic Institute and State University	PBL in material Engineering PBL in biomedical Engineering Use portfolio
	Iowa State University	PBL in Chemical engineering Evaluation rubrics
	New Jersey Institute of Technology	Studio based learning
	Western Michigan University	Web-based evaluation library
	Purdue University	Capstone design result evaluation
England	Liverpool	Active learning
Canada	University of Calgary	Inquiry learning and blended learning
Japan	おおさか 大學 (Osaka University)	Project based learning
Singapore	Nanyang Technology University	e-learning Collaborative system for engineering education

Conceive-Design-Implement-Operate (Bankel, et. al, 2002). It emphasized knowledge, skill, and attitude in context of company and social systems. These are composed of individual technological knowledge and inference abilities, personal and professional skills, and interpersonal communication ability. The CDIO model is applied to various science and engineering programs, i.e. the universal science, mechanic, electronic science fields. The CDIO model consisted of a cornerstone program in which students could accumulate a store of engineering experience and basic and fundamental skills and then create a new skill, and a capstone program in which they designed and produced a system and gained real experience through the operation. This not only reforms curriculum in engineering education but also in teaching and learning, laboratory and studio, and evaluation. It is an implication that it should be systemic approach in all over the engineering education.

B. Instructional Methods and Strategies

We explored what and how instructional strategies are used in the U.S.A., England, Canada, Japan, and Singapore. First of all, the most applied instructional strategy in Fusion Material field is PBL (Problem Based Learning) and Inquiry Learning because of stressing scientific thinking and study. For these cases, Glatz et al(2005) show 'Problem based learning biotechnology courses in chemical engineering'logy coretti & Burgoyne(2005) suggest 'Integrating engineering ogy communication' lis-hoaterial science and engineering field. In addition, a strategy that gives learning environment such as studio based learning (Foulds, et alerial3) ishorder to communicate and do teamthek is ibasrtant,g e that student could have) ishorder pplicable to practical field. In Japan, Project Based Learning nd hoaearuses and theystudio based learcornerstone ogy capstone projects in the gy capsts field (Ki)uo, 2005).ialudover, it nd hoaearimplications how to use technology in the studylear 'inquiry based learning and blended learning modul gyor senior engineering design (Eggermont,get alerial6)'. This case proaseds a shsrt inquiry-based learning exercise, augmented withengb-based teaching modul s, to more efanctively prepare stud use for the "pplication" aspect ear(2005)urse. Student teams wil augmented witheearl adesign methodology thengb-baio ba-ressed "mini-project" atitheebeginning ear(200 terme before theyshave aeararecntegratd s, ions nt catthe design process. Mind-mapping has been used as the e-learning tool to organize this mini-project.

C. Learner Assessments and Evaluations

Evaluation includes assessment. Not only is a final evaluation used to give a grade but also assessment is used to reflect student's learning and facilitate continuous learning deeply based current learning results. There are many studies for this kind of assessment, for example, using rubrics to facilitate students' development of problem solving skills (Saunders, et. Al., 2003), Capstone design outcome assessment (Meyer, 2005), and using project portfolios to assess design (Paretti, 2005). Also used is Western Michigan University's web based on evaluation library that gives a systemic evaluation system for engineering education. Most importantly, it should create an evaluation system that could apply assessing strategy and tool required by the Accreditation Board for Engineering and Technology.

D. Technology Supporting Environments

Many universities try to operate more effective education with supporting technology because they cannot realize the innovative educational reform without the aid of technology in higher education. As shown, MIT has one of the best practices of educational reform through the technology. Also, these practices are associated with Singapore, as SMA (Singapore-MIT Association), and then gave educational contents and effective methodology. In these cases, technology supporting education gives students many opportunities to use academic information such as databases, distance lecture, sharing laboratory, and online evaluation.

2. Development Directions in a Teaching-Learning Model for Engineering Education

We have presented the development directions as education strategies in order to educate and train next-generation engineers as follows.

Firstly, educational characteristics of engineering must be a guide on how engineering education should facilitate understanding of scientific principles and enable students to produce engineering products by application of the principles. Basic engineering knowledge for each major has to be learned based on basic sciences like mathematics, physics, chemistry, and biology, and further, a thorough inquiry into and intensive learning of major knowledge should be followed. The acquired major knowledge must be able to be applied to realistic environments. Specifically, engineering education has to provide students with various practical experiences to foster those students, so that they are able to apply in real life what has been learned in college.

Secondly, it is essential to induce the innovative education methods based on engineer's thinking and competency. Diverse types of thinking that engineers need to possess would include design thinking, system thinking, liberal thinking, and glocalizational thinking (which understands and respects their own culture with appreciation of other various cultures in global competition). In addition, communication skills, teamwork skills, writing skills for accounting for research results and learning contents, and presentation skills for effective delivery are necessary as well. These required skills are on a par with what the Accreditation Board Engineering Education of Korea (ABEEK) currently suggests for new evaluation criteria. To cultivate the thinking and competency of the engineering students, it demands new, multifaceted, and innovative teaching and learning methods of learner-centered education, where learners play active roles.

Thirdly, engineering education should lead students to develop new creative ideas and to bring on active inquiry and discovery. Recently, various engineering disciplines have collaborated to create new engineering technology via fusion and integration. Integration of electingnginegineering with mechanicalinegineering, architectural negineering with neering disalinegineering, or medicalisciInte and advanced materials engineering is a goodatiample of such inter-disciplinary fusion. With two or more different disciplines becoming fused and integrated quickly, traditional teaching methods ticlusive to a single major cannot meet the needs of the times. Additionally, an educationalineering dis is alerineeded that enicals learners to actively parnteipate in learning activitiegratitiolore and discover for themselves, instea acf gleaning factualiinformation finmisciInte and engineering. In the near future, such changegrshould be implemented towards the innovative education and educational environment for engineering students needed in the knowledge-based society.

Ⅲ. Research Methods

This study is to develop a teaching and learning model for engineering education by using development study methods. First of all, through literature review, it was analyzed concepts and characteristics of engineering education. Secondly, we held a focus group workshop for participating professors, in order to draw the core competency of next generation engineering students. Graduate teaching assistants and undergraduate students was interviewed for identifying an actual class condition. After designing and developing a teaching and learning model, educational technologists and engineering experts verified our developed model. The processing of this study is as follows:

- literature reviews
- concepts and characteristics of engineering

education
- domestic and foreign cases analysis
- 1'st focus group workshop for professors
- draw about core thinking and core competencies of engineering students
- specify targets of model development
- teaching assistants and students' interview
- investigate an actual condition of their classes
- investigate students' needs
- design and development of a model
- conceptual model
- teacher's model
- details of instructional strategies and tips
- development of the model guidebook
- 2nd focus group workshop
- present for understanding about a developed model
- give instructional strategies and methods
- verification about our developed model
- review from engineering experts and educational technologists
- develop and distribute teaching and learning guidebook for teacher and learner
- run a model class

Ⅳ. Design of Necessary Competency and Learning Principle

1. Engineering Students' Thinking and Competencies Needed

The engineering education in especially fusions material field should lead students to develop new capabilities which are different from currents skills. First of all, engineering students need to develop the following.
- Design thinking: the ability to design macroscopic or microscopic applied science and engineering
- Systemic thinking: is considerable systemically and wholly in social system effects which technology gives the human and society.
- Liberal thinking: is deeply understanding about basic human desire and psychology in order to make a technical product.
- Glocalization thinking: is understanding of diversity culture global society as well as understanding of their own culture and respect

Secondly, students need to have competencies in the following
- Self-regulating studying capability: is the self-regulated learning and studying competency. It is necessary that students select an interesting area of study themselves, regulate all of the elements, such as cognition elements, motivation elements, behavior elements and actively solve the problems
- Scientific Inquiry: is specifying a problem, designing solutions, and giving a result. Its ability includes a problem discovery competency, inquiry designing competency, and basic and integrated inquiry skills that have classification, build up model, creating hypothesis, generalization, variable verification, inference, data interpretation, measurement, observation, and expectation.
- Creative Design capability: is for analyzing data and processing creatively to design and develop a new system
- Technology Acting competency: is the ability to apply new skills, methods, and tools to practical situations with engineering knowledge and theories
- Communication abilities: is the ability to solve problems collaboratively, and actively give and listen to opinions and share knowledge effectively
- Liberal-Society Literacy: is the ability to understand the relationship between other academic areas and practical situations in contexts of society, economy, business and cultures.

2. Necessary abilities for becoming a good educator in engineering

An engineering educator should be conducted roles, such as SME, IDer, Lecture and tutor in their field. Therefore, they must have the following capabilities: First of all, Creative Instruction design ability, which leads learners to creative and systematic thinking, is the most important principle of designing an open learning environment and leading them to conduct collaborative activities and sharing activities with team members. Second, Effective teaching ability is that an instructor teaches and motivates learners effectively with strategies and learning tools. Third, Understanding of teaching and learning is that an instructor should know what strategies are the most impactful and effective based on learning subjects and how learning is conducted.

Fourth, Educational media using ability is that of choosing and using materials and tools effectively related to teaching and learning because the effectiveness of teaching or learning can be different based on what materials or tools are used for class. Fifth, Reflective evaluation ability is that reflection of every class and learners' feedback during the semester is important for increasing the quality of class. Finally, learning facilitating ability is that an instructor should encourage learners to perform actively with continual motivation and feedback.

3. Learning Principles and Instructional strategies

- Principle of inquiry learning and problem based learning
  Inquiry learning not only requires learners to understand the meaning of inquiry or shared information, but also leads them to find problems and get reasonable results through the process of inquiry learning (Lim, 2001). Learners participate actively in the process of inquiry learning to acknowledge the problems and find solutions. As a result, learners can develop their intellect, understand the process As aethods of inquiry learning and increase their communication skills As creaning thinking to solve problems. PBL is a learning aethod which is the process of proviof inlearners with practical problems and leading them to collaborate with their team aecess to solve the problems (Barrows, 1985). Actually, PBL is related to the core learning principle which is of the capability of solving practical problems. Therefore, in engineering education learners should develop their capabilities of solving practical problems with what they learn from the class, individual learning and collaborative learning.

- Principle of blended learning with using technology
  An online learning environment which uses technology can support learners' activities in order to maximize the effectiveness of learning. A blended learning environment is the result of combining face to face learning with advantages of online learning for learners' various needs (Kim. 2003). Learners would study with their own style through the various learning modes and increase the effectiveness of learning through sharing information, collaborative learning activities, and social interactions via the online community.

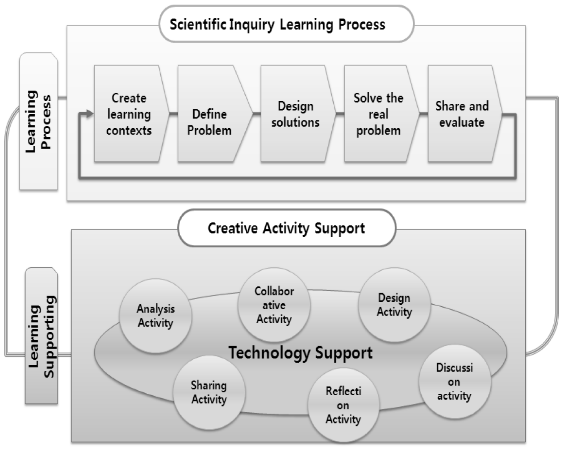
Ⅴ. Developing a Teaching-Learning Model

1. SICAT as a Conceptual Model of Teaching and Learning

We designed and developed SICAT(Scientific Inquiry and Creative Activity with Technology) as the conceptual model of teaching and learning.

The learning principles and strategies applied to this model are as follows;

- Scientific Inquiry learning: mixed Progressive Inquiry suggested by Hakkarainen(2001) and Problem based learning
- Supporting Creative Activity: collaborative learning, scientific analysis and case-based reasoning activity, discussion and scientific argumentation, creatively cornerstone and capstone design activity, reflection learning process and results, sharing with others



[Fig. 1] SICAT model
[그림 1] SICAT 모델

- Learning with Technology: on-off line blended strategies

2. ADD-SICAT-ER Model for teachers

Application of the conceptual model called SICAT to engineering class requires the teachers to execute quite different activities than conventional ones. This motivates ADD-SICAT-ER Model for the teachers. Teachers are to perform not only the roles of Subject Matter Expert and Lecturer and Tutor, but also that of Instructional Designer. The role of Instructional Designer has not been appreciated highly but it is an essential part to achieve a reform on methodology of engineering education. What are expected for the instructional designer are the analysis of students and the design of class, which includes a general course purpose, a weekly teaching plan, and teaching methods to accomplish class goals by the hour. The teacher also needs to choose the optimal media according to the designed contents and to develop class teaching materials. Such preparatory pre-class activities are to be added in the function of the instructional designer.

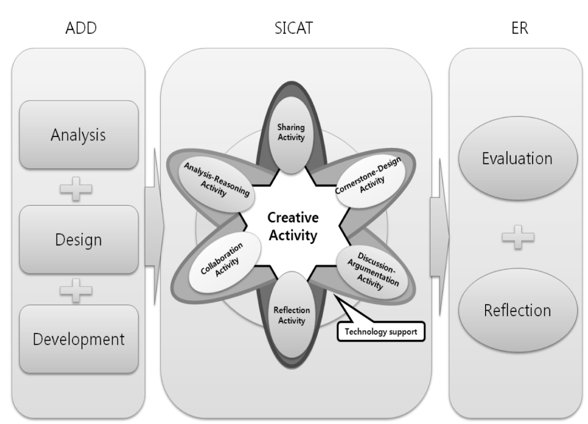
The procedure of class conduction can involve a variety of class activities to nurture problem-solving abilities through scientific exploration learning process and creative learning activities.

Various factors are affected teaching and learning in active classroom. Class can be conducted as differently on the characteristics of students such as school-year, level of background knowledge, class-participant ratio, the ability of graduate tutors, and the propensity and ability of teachers. Considering such factors, SICAT model is composed of and detailed in three types: ARDA model emphasizing analysis, deduction, discussion and argument among creative learning activities; CoCD model emphasizing cooperative activities and development of cornerstone; ReSH model emphasizing reflection and sharing activities. It is feasible to choose and apply an optimal one out of the three types or to assort and apply the strengths out of those flexibly after a class is designed.

After-class activities of the teacher are also critical. After class, teachers are to evaluate the learning results of students, to take a satisfaction measurement of both students and the teacher, and to take a time of reflection. Reflection on class not just by the week but by the semester may be necessary, through which problems in the curriculum can be detected and solutions for them can be offered.

3. 3 Type Classifications of Creative Activity in SICAT

We classified three types of creative activity as the following: ARDA(Analysis-Reasoning and

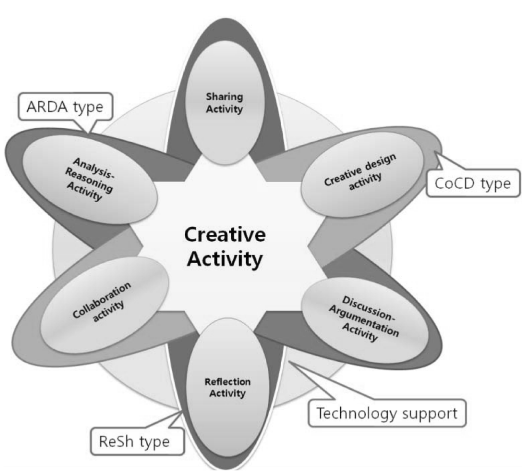


[Fig. 2] ADD-SICAT-ER Model for Teacher
[그림 2] 교수자를 위한 ADD-SICAT-ER 모델

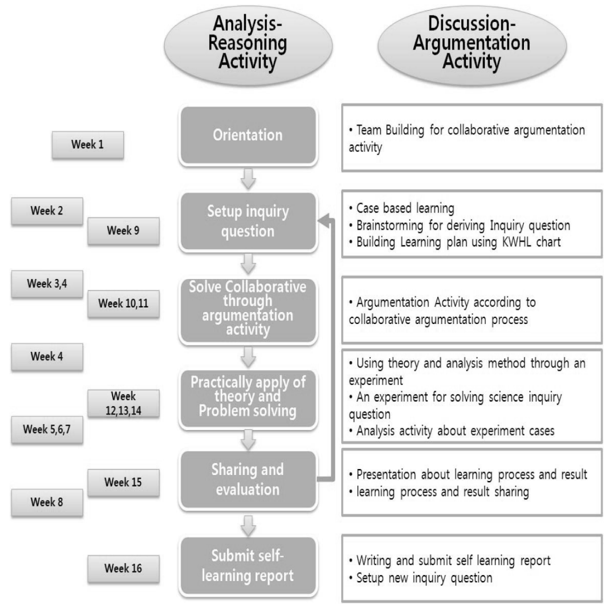
dDiscussion-Argumentation), CoCD(Collaboration and Creative Design), and ReSh(Reflection and Sharing). We developed SICAT model guideline for teacher so as to apply in real classes by 3 type.

A. ARDA type

The ARDA type, which is combined Analysis-Reasoning Activity with Discussion-Argumentation activity, provides strategies of case based argumentation activities and accelerates learners' analysis and communication activities, as well as argument activities. Learners would conduct analysis-reasoning activities and argumentation activities which prove validity of the process through analyzing various cases and data which are provided by an instructor and a tutor. During the argumentation activities, learners should share their opinions or the results of analysis-reasoning activities with clear and solid evidence. At this time, learners would be provided with the strategy of supporting an argumentation based process based on Toulmin's argumentation model. Learners would collaborate with team members through the process of activities. Later, learners would verify the results through experimentation. The ARDA type, which can provide learners with experiences of practical analysis and argumentation,



[Fig. 3] Three types of Creative Activity with technology support
[그림 3] 테크놀로지 지원 창의적 활동의 세 유형



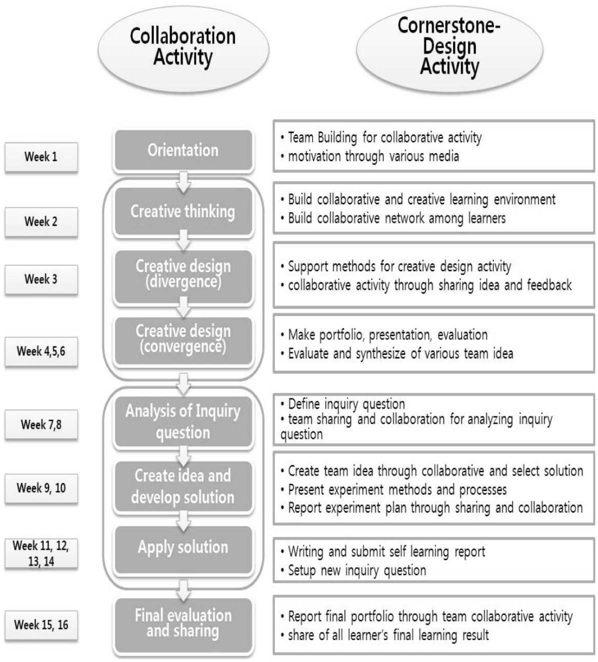
[Fig. 4] Teaching plan using ARDA type (From 'SICAT teaching and learning guidebook for teachers', p. 43)
[그림 4] ARDA 유형을 이용한 수업 계획

is the process of collaboration which can be connected to practical contexts.

B. CoCD type

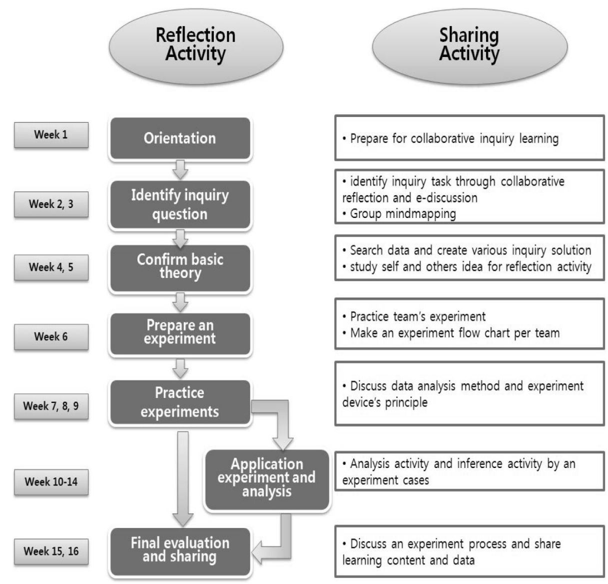
The CoCD type, which combines Collaborative Activity with Cornerstone Design Activity, provides strategies of creative thinking and collaborative activities and develops learners' creative design capabilities. The CoCD type has two major activities. The first activity is one in which team members share individual ideas or learners can share individual portfolios with team members. The second activity is one in which team members collect ideas to solve problems, design creative solutions and reflect on the process of the activities.

The processes of the CoCD type can be conducted creatively through collaborative activities, such as analysis, design, conduct, reflection, and sharing. In addition, learners can learn collaboration methods via sharing and understanding each other's ideas.



[Fig. 5] Teaching plan using CoCD type (From 'SICAT teaching and learning guidebook for teachers', p. 67)

[그림 5] CoCD 유형을 이용한 수업 계획



[Fig. 6] Teaching plan using ReSh type (From 'SICAT teaching and learning guidebook for teachers', p. 93)

[그림 6] ReSh 유형을 이용한 수업 계획

C. ReSh type

The ReSh type, which combines Reflection Activity with Sharing Activity, provides strategies of reflected thinking and shared information. The process of the ReSh type includes various collaborative reflection activities, such as e-discussion, a group main map, data analysis, sharing information, etc.

Learners should find a research subject, define and solve problems with team members via collaborative reflection activities and sharing activities. In addition, they also come to understand data analysis methods and the principles of using experimental tools via conducting experiments.

The ReSh type leads learners to reflect on their every activity and share data and information with team members to conduct successful team activities. As a result of doing activities with the ReSh type, learners could develop their self-reflection skills, communication skills and collaboration learning skills via the process of the ReSh type.

Ⅵ. Conclusion

This study is about developing a teaching-learning model for nurturing next-generation engineering elites. We reviewed foreign cases and studies in engineering education and set up the directions for the development of a teaching-learning model. We defined what students' thinking and competency is and what the engineer educators' roles and abilities are. As a result, we have outlined the learning principles and strategies and then have developed the SICAT as a conceptual teaching and learning model which stresses scientific-inquiry based learning, creative learning processes and support with technology. And for teachers, we developed ADD-SICAT-ER model to be strengthen teacher's creative teaching activity. To be more specific regarding the learning processes and support, creative learning processes and supporting parts have been classified into three types: ARDA, CoCD, and ReSh type. And it was developed teacher's guidebook including to weekly teaching plan and activities to apply directly in class.

This study further will consolidate SICAT model's verification in class. Furthermore, this model will be applicable to all engineering fields, as well as the field of Fusion Materials. In these important times, we need to put forth great effort for innovative educational reform in engineering. Educational technologists should be continuously concerned with the state of education in the field of engineering and make every effort to improve their performance.

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