A conceptual framework to develop a project management system with multidisciplinary consilience in the capstone design course

Moon-Soo Kim

Hankuk University of Foreign Studies
Yongin City, Republic of Korea

ABSTRACT: In order to cope with the increasing demand for multidisciplinary learning in commercial realities of industrial practice for the creative economy, a consilience-type teaching and learning model and related operational tools or software enabling applications to engineering education are essential. This study proposes a conceptual framework with embedded multidisciplinary consilience and project-based learning as an initial step for the development of a Web- and mobile-based integrated system for students taking the industrial engineering capstone course. This course would help them design, implement and improve the solving process of industry-related problems through the integrated approach and thinking with multidisciplinary consilience knowledge among humanities, social science and engineering disciplines.

Keywords: Conceptual framework, capstone design, project-based learning, multidisciplinary consilience, industrial engineering

INTRODUCTION

The core competitiveness of the 21st Century's economy is based on creative capability. Further, as its originators, creative human resources have become a key concern of industry sectors, as well as engineering education. In the case of technology, such as IT (information technology), BT (biotechnology) and NT (nanotechnology), research and development for the convergence between areas has attracted huge investment and expansion in both the private and public sectors. Education for technology fusion, a new multidisciplinary programme for consilience as the long-term plan, has been developed with a focus on graduate and engineering schools in Korea. However, there are few programmes for current undergraduate engineering schools to promote consilience among multidisciplinary fields.

In order to cope with the increasing demand for multidisciplinary education to facilitate the creative economy, the application of a consilience-type teaching and learning model, as well as the related operational methodology and tools, such as Web- and mobile-based integrated information system, are indispensable. For students taking capstone design as a graduating course in undergraduate engineering school, this study proposes a conceptual framework with cooperative project-based learning processes and multidisciplinary consilience as a nascent step for the development of a tool. This tool could be designed and implemented to help improve the performance of students in the process of solving industry-related and practical problems by themselves through an integrated approach based on the multidisciplinary consilience knowledge from the humanities and literature, social science and engineering disciplines.

The article deals with multi-disciplinary consilience knowledge, including recent trends in industry and in the public sector regarding consilience, student-centred learning theory and capstone design course of engineering education. It also describes the industrial engineering (IE) capstone course in Korea, and proposes a conceptual framework that will be used to design software that will enable application of multidisciplinary consilience knowledge to the IE capstone project.

LITERATURE REVIEW

Multi-Disciplinary Consilience Issues and Engineering Education

This study was motivated by the concerns of the private and public sectors regarding convergence within and/or between technologies and industries, which may facilitate technological innovativeness for increasing economic capabilities [1].

Such concerns have naturally moved on to comprehensive strategies, which would enable the convergence of the technology, industry and academic domains. Engineering education is one of the most important areas of the academic domain in which to provide education regarding convergence. In the academic domain, consilience terminology seems to be more prevalent than convergence. Consilience, which was initiated by Whewell, is the unification of knowledge applied to the humanities, art and literature and social and applied sciences, using analysis methods and the integration of reductionism and holism [2]. Consilience manner has become a core source for economic areas, such as technology innovation and competitive environment. Mechatronics, as an area of technology fusion, for example, has been a key source of innovation and industrial competitiveness in the manufacturing sector in Japan since the 1970s [3][4]. Furthermore, future creative industries will need many more consilience-type human resources from engineering education [5].

Figure 1 describes six types of convergence within and/or between technology, industry and disciplinary domains based on the definition of convergence of technology, industry and academic domains by the National Science and Technology Commission (NSTC) of Korea [6]. Among the various types, this study is focused on Type I, multi-disciplinary consilience, and Type VI, consilience between discipline and industrial domains. Practical and professional problems from Type VI, which are necessarily multi-disciplinary, can encourage students of engineering schools to solve problems through a collaborative learning process and multi-disciplinary consilience knowledge from Type I.

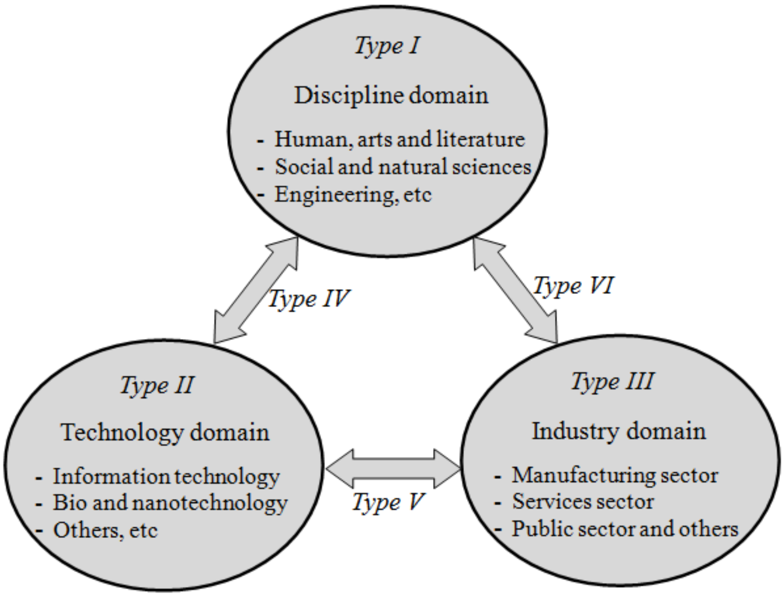

Figure 1: The convergence types within/between technology, industry and disciplinary domains (revised and adapted from NSTC [6]).

According to a recent empirical study on technology-humanities convergence for small and medium enterprises in Korea, social science and humanistic studies have played an important role in the innovation process [7]. Above all, such disciplines may serve as a tool to enable communication among participants in relation to innovation, as mediated through products or technology. Because social science and humanistic studies are related to communication themselves, as well as being communication-enabled disciplines, they help activate open innovation based on the outcome of effective communication between inside and outside creative innovators of a company. Secondly, creativity, derived from imagination and based on social science and humanistic studies, has also been highlighted in the commercial world. Such creativity and technology may be the origin of breakthrough innovations, as in the typical example of Steve Jobs' Apple. Thirdly, social science and humanistic study, fundamentally, seek the value of humans with much higher priority than productivity in the process of product and technology development. Such features and elements of social science and humanistic studies are essential for future engineers.

Student-Centred Learning and Engineering Education

Student-centred learning, which refers to the imposition of more responsibility on students for their own learning than the traditional lecture-based approach, is an umbrella encompassing a range of instructional methods, including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, etc. These methods are all supported by research findings that students learn by fitting new information into their existing cognitive structures, and are unlikely to learn if the new information has few apparent connections to previous knowledge and beliefs [8]. As most engineering educational institutions are in an ongoing process of transformation from the traditional paradigm, which is discipline-oriented, lecture-centred, and based on basic and applied technical knowledge, to a new, interdisciplinary, contextualised, student-centred paradigm based on a complex understanding of technological knowledge, the implementation of problem-based learning (P_mBL) and project-based learning (P_tBL) have been highlighted more and more by those institutions [9].

In terms of theory, the understanding of student-centred learning takes its point of departure in the constructivist-sociocultural approach of understanding learning and education, building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing the versions presented by their teachers [10]. The methods almost always involve student discussion about questions and problem-solving in class (active learning), with much of the work inside and outside of class being done by students working in groups (collaborative or cooperative learning). Many different variations of student-centred learning practices may be identified, ranging from the large-scale implementation of student-centred learning at a departmental or institutional level, to the small-scale implementation in a single course [9].

P_mBL is a learning process based on a peculiar problem case under the need-to-know method [11]. For appropriate application of the P_mBL model to engineering education, P_mBL needs a multidisciplinary approach that can provide information and knowledge, as well as certainty, to engineering students dealing with problems with which they are not experienced and that are ill-structured [12]. In addition, under the P_mBL environment, teachers or educators are not a source of knowledge, but should instead be the guide or coach facilitating the process of knowledge acquisition for the students [13][14]. The P_tBL model in the engineering school is a kind of P_mBL, since project work is problem-based by definition and its process usually deals with problems from real industry sectors. The P_tBL process of ill-structured problems requires the employment of various multi-disciplinary fields to yield solutions to the real industrial problems [12-17]. In identifying how to reach the project goal, the members of a team have to learn to co-operate effectively. This creates good conditions for learning, as it involves both individual and co-operative activities, as well as interactive discussions and a writing process (mostly in the form of a project report). Project work teaches competencies, such as project management and co-operation. Project assignments are also highly challenging. The more the task reflects reality, the more the students feel motivated, so working on a project can be seen as a way to organise various simultaneous and/or integrated learning processes [18]. Therefore, it is crucial for the students in a P_tBL curriculum to become lifelong learners who have learned to take responsibility for their own learning process. This is why the capstone course of senior students is deep associated with the P_tBL process.

CAPSTONE COURSE IN ENGINEERING EDUCATION

The capstone design course seeks to prepare engineering students for work in industry by challenging teams to synthesise solutions to open-ended, real-world problems, typically through the employment of project-based learning activities based on industrial problems [19][20]. In most engineering schools, the capstone course has been applied to senior students as a gateway to achieving their academic degree. Typically, in one or two semesters of the course, teams define a problem, plan their approach, propose creative solutions, analyse the proposed solutions, produce or implement the solutions, and then communicate them internally and externally. Participation in capstone design provides students with the opportunity to transition from student communities of practice to professional communities of practices, i.e. from the classroom to real industry. Working with a client-advisor from the field (industrial engineers, start-up companies, company representatives, teaching staffs, laboratories, etc) in a type of apprenticeship, students are challenged with real-world needs. While the students in the capstone course are not full members in the professional community, contextualising the problems, needs or services within the field's practices provides the students with the opportunity for situated learning and affords them the opportunity to apply their skills and knowledge toward the development of a robust understanding of what it means to be an engineer [21]. This facilitates an identity shift from student to professional engineer [22].

In recent studies, the employment of multi-disciplinary knowledge across various engineering fields has been shown to have a positive effect on the project process, enabling students to produce more creative outcomes [17][23]. The course participants (students, teaching staff and industry participants) could benefit from having a more multi-disciplinary capstone experience within engineering domains, with the team members representing more than one discipline working on similarly posed problems [17]. Most compellingly, since these engineering students will need to survive and thrive in multi-disciplinary professional environments after graduation, the engineering environment needs to seek to inculcate as many lessons as possible about the inherent challenges and opportunities beforehand. As of 2005, approximately 35% of engineering capstone design courses included interdepartmental or multi-disciplinary teams, representing an increase from 21% in a 1994 survey of 1,724 programmes at 350 institutions in the US [23]. However, while multi-disciplinary consilience knowledge with the humanities, art and literature, and social science plays a mediation role in the innovation process, and is a source of imagination for creativity, keeping the value of the humanities in mind when applying engineering technology in reality, there are few theoretical and empirical studies on multi-disciplinary consilience knowledge with the humanities, art and literature, and social science for engineering education [7]. Besides, no evidence has been provided of the positive effects on multi-disciplinary consilience projects.

A CONCEPTUAL FRAMEWORK FOR PROJECT MANAGEMENT SYSTEM EMBEDDED MULTIDISCIPLINARY CONSILIENCE

Course Framework and Description of IE Capstone

The industrial engineering programmes in most of the world's universities have interdisciplinary features based on many diverse courses, including those in areas, such as the social science, management and economics disciplines, which can be divided into six mutually exclusive categories [24][25]. This feature of IE might encourage students to adopt and use multi-disciplinary consilience with the humanities, art and literature when conducting the capstone project at the senior level. The industrial engineering capstone course of Hankuk University of Foreign Studies (HUFS) in Korea lasts 15 weeks, and is mandatory for undergraduate IE students in their seventh semester. Students are required to work in teams of three to five students in order to develop a real project. Although the projects are based on real problems, they come in diverse types: projects formulated by students themselves from needs of the industrial sector, projects proposed by faculty members from their private or public contract R&D projects, projects proposed from within the engineering school, projects based on subjects of competitive exhibitions held by outside institutions, etc. Among the various types, student-owned projects are typical and have been encouraged by this course. While execution of the course during one semester is based on the general procedures of project management by every project team without lectures, consisting of three regular steps including the proposal, interim and final evaluation, the preparatory step undertaken by students before the start of the course is very important for team formulation, project selection and pre-survey about their project, etc, and the post step for the application of the project results obtained is essential for their future carriers. Thus, the overall capstone course may be comprised of three courses: a pre-course, as preparatory study; a class-course, as a regular course; and post-course, including typical application activities. The IE capstone course is a totally project-based learning process containing the six elements of the project-based learning model proposed by Palmer and Hall: seeking the solution of a problem or completion of a task requiring students or teams to complete a project; performance of non-trivial and often multi-disciplinary projects; development of a concrete artefact; requirement for a written report and/or oral presentation describing the project methods and the final results; and the advisory role of teaching staff [26].

The pre-course of capstone is usually carried out for four to six weeks during the vacation season prior to the new semester. At that time, students spontaneously formulate project teams with a minimum of three to a maximum of five members. Every team, then, receives an industrial problem from a service or manufacturing company provided by the faculty members, alumni or the team itself, and prepares to solve the team project through identification and definition of the team problem, surveying the target company (which can be a client), drawing up an execution plan (including assigning detailed tasks to team members), and execution of student-centred learning to gain the relevant knowledge and information about the problem and company. Although students meet the faculty members for discussion and advice about the problem during the pre-course, all activities and learning for project formulation are autonomously carried out by the students. At the end of the pre-course, each team prepares a project proposal and an oral presentation.

The class-course of capstone, which is a five-credit class with a professor in charge and the advisor-to-team, begins with oral presentations by all teams in the first week, which is an official event open to the all students of the IE department, after which the proposals reflecting the faculty members' comments and peer review are submitted in the following week. Throughout the duration of the course, all teams carry out their projects through collaborative learning, weekly meetings with advisors and communication with their industrial clients. Although there are no official lectures, monitoring and control of the progress of all capstone projects is performed through oral presentations of the intermediate results, and the mid-term and final-term outputs of each team are officially evaluated by all faculty members and peer review as done for the proposal evaluation step. In the case of industrial projects, the outputs are, then, delivered to the related companies, whose feedback must be included in the final report, which signals the end of the class. The students' grades are determined on the basis of the three evaluations, peer review and/or company feedback, including on the quality of the project output, as well as the advisors' judgment on how well the team worked together and kept to schedule.

The post-course is for utilising the project outputs to help students in their future carriers. It contains areas, such as financial support, advice by faculty members, and relevant information and institutional assistance when submitting the project output to a university, inside or outside competition exhibition, submitting papers to academic journals and patent application.

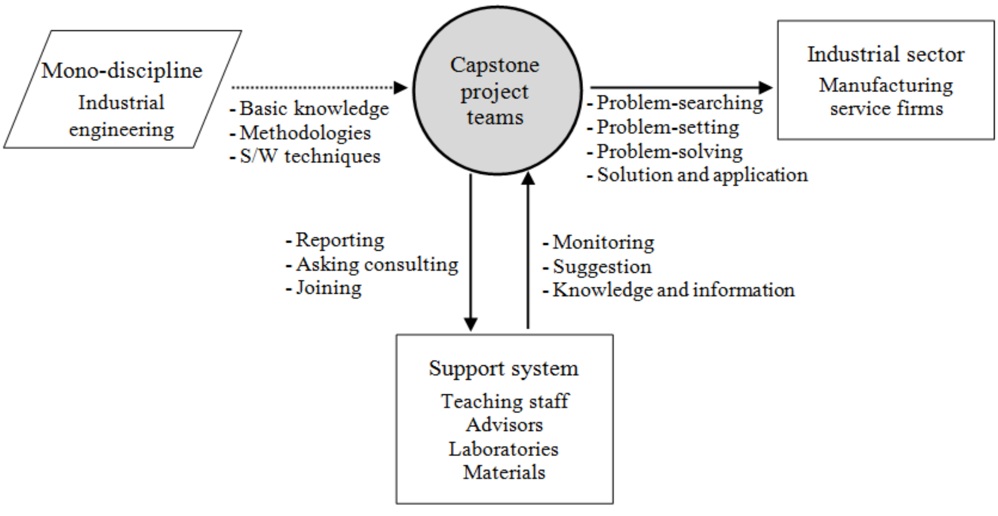

Figure 2: The current framework of the IE capstone course.

Figure 2 shows the current framework of the IE capstone course described above, which consists of three parties, including the participants as a student team, the industry sector and teaching staff involved in the execution of the course, as well as one discipline of IE as a knowledge base, where solid lines indicate student team activities to conduct the project work. This includes problem-searching, -setting, -solving and seeking a solution, its application, reporting, asking for project-related consulting, etc, or the teaching staff's support activities. The dotted line represents the use and application of IE knowledge and methodologies by students to solve the project.

From the birth of the IE capstone course to the present, the overall process has been managed by the traditional teaching methods in a class. Such off-line management has shown several pitfalls in both of course management of the teaching staff and project management of the student teams. The capstone course-specific features require historical records linked to previous projects, which would enable students to search for and define projects without much time consumption, as well as to obtain effective and efficient methodologies with which to solve their problems, if the capstone course history were to be available via an on-line system. Furthermore, the on-line management of the capstone course can provide both teaching staff and student teams with more efficient monitoring and progress control for the capstone projects. However, the standard project management tools, such as Scrum of software engineering, which has several beneficial effects for improving management of the development process and customer relationships [27] and decreasing the amount of overtime [28], are not appropriate for the IE capstone course because of the ill-structured and open-ended nature of the problems, which deal with multi-disciplinary subjects from a range of industrial issues. In addition, business-use project management software is also unsuitable for the management and evaluation of the student projects and for communications with the various participants. Therefore, the on-line project management tool for the IE capstone course needs to be designed for IE discipline-specific pedagogical purposes, and above all, has to provide a suitable environment for student-directed collaborative learning, with access to consilience knowledge from multi-disciplines for the solving of practical industrial problems.

A PROPOSED CONCEPTUAL FRAMEWORK

The capstone course of engineering schools is fundamentally based on project-based learning, which requires student-directed and collaborative learning, and is more directed to the application of knowledge. Moreover, the management of time and resources by the students, as well as task and role differentiation, is very important in project-based learning [29]. From both the perspective of the learning theory and practical execution with outside participants, such as firms or institutions, an on-line tool for management of the capstone project is prerequisite for students to maximise the learning effects of the capstone course, and may provide a cycle of virtue for future students.

The literature review on the recent trends of industry demand, such as demand for multidisciplinary consilience knowledge in engineering education and the experiences of capstone course execution, led to the development of the following conceptual framework, which will be used to design software enabling the application of multidisciplinary consilience knowledge to the capstone project. In Figure 3, while the boxes, circle and arrows in solid lines simply show the current framework of the capstone course, the new elements are highlighted with dotted lines, representing the characteristics of the conceptual framework with embedded multidisciplinary consilience for the IE capstone course.

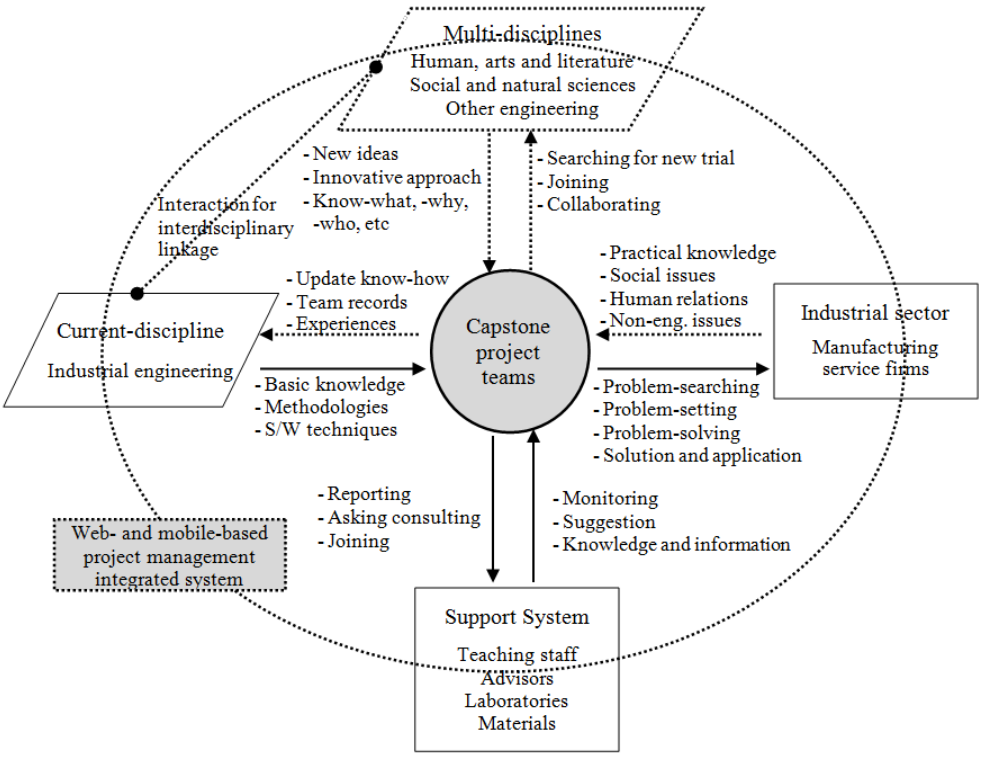

Figure 3: A framework for embedded multidisciplinary consilience in the IE capstone course.

Under the framework of embedded multidisciplinary consilience, project teams are required to conduct much more diverse work than under the existing framework, such as closer interaction with industrial sectors, and new responses to both their own discipline and other disciplines. As numerous studies have indicated, today's engineers need to have a broader perspective of the issues concerning their profession, including the social, environmental and economic issues [23][29][30]. Closer interaction with the matching project-related company would allow the students to obtain more practical knowledge about the social, organisational, legal and environmental issues, which would help them seek better solutions in reality. The data, information and knowledge gained through, such a close interaction should be stored and updated inside the software to provide a historical record and know-how for future students of the capstone course.

As mentioned, project-based learning process requires the implementation of multi-disciplinary knowledge to create ideas, develop innovative methodologies and produce solutions for ill-structured problems based on the industry sector [12-14][16][31], which has positive effects on the project process efficiency and allows the students to obtain more creative outcomes [17][23]. Further, as one moves into the 21st Century, the need to cross and mesh disciplinary boundaries is increasingly evident, because new knowledge is increasingly created at disciplinary interfaces [32]. Besides inter-disciplinary knowledge among the applied sciences and engineering domains, consilience with social science, humanities, arts and literature, which may play a mediatory role in the innovation process and is a source of imagination for creativity while keeping the value of the humanities in mind for technology application [7], is becoming an essential prerequisite for engineers in the 21st Century.

Under the framework of embedded multidisciplinary consilience, students as capstone teams can have many opportunities to consider new ideas, and deal with innovative approaches and unfamiliar knowledge, such as the know-what, know-who and know-why of the process, rather than simply know-how that help them perform the problem-solving process more effectively. In order to get such opportunities, they need to cooperate with parties of multi-disciplinary domains, which may include faculty members or the students of other domains. Furthermore, they can also take part in cultural courses or join the department of those domains as a dual major, acquiring a second Bachelor degree in social science or humanistic studies. In a similar manner to the interaction with the industrial sector, students are required to store and update the data, information, knowledge and experiences from the multi-disciplinary domains for future capstone courses.

Overall, while the proposed framework conceptually allows students in the capstone course to solve diverse problems within their project and develop a final output through utilisation of multi-disciplinary consilience and professional knowledge in the reality of the industry sector, there are many miscellaneous and routine tasks, as well as frequent interaction with various stakeholders, for the students to carry out the capstone projects. Thus, the proposed framework contains a tool using information technology, besides the general functions for project management, through which a Web- and mobile-based project management integration system supports the interaction between participants using wired and wireless Internet, including smart phones and tablet PCs. It must also hold a data base (DB) subsystem responsible for the storage, update, and delivery of the data and information obtained from such interactions among the various participants in the capstone course. Eventually, the DB system within the tool is expected to evolve into a self-proliferating knowledge management system that can formulate, collect, accumulate and share multidisciplinary consilience knowledge from the team collaborative learning process, project execution experiences, and interaction with the industrial sectors and relevant discipline domains.

CONCLUSIONS

The previous literature on the highlights of multi-disciplinary consilience knowledge including humanistic studies, student-centred learning theory and the capstone course in engineering was reviewed. Specific attention was given to the importance of multi-disciplinary consilience knowledge among various academic domains, and the practical knowledge from industrial sectors as inputs for this framework for engineering education. The interactions between students and multi-disciplinary domains, as well as between students and industrial participants or teaching staff, will facilitate the exploration, transformation and exploitation of problem-solving knowledge. The student-centred learning mechanism totally guaranteed by the capstone course drives such interactions. This is synthesised in the proposed conceptual framework, which has several implications and limitations for future research and practice in engineering education.

This conceptual model can be used to guide future research in multi-disciplinary consilience initiatives within engineering education by paying specific attention to the underlying student-centred learning and interaction with the industrial sectors. A possible venue for new research would be the use of longitudinal case studies to obtain more detailed insights into how learning occurs, and how successful projects are realised through student-centred learning mechanisms in the capstone course, hence, allowing the development and use of multi-disciplinary consilience, especially in humanistic studies and practical knowledge obtained from the industrial sector.

A single in-depth case study on a specific department might also be useful, where detailed insights are collected on a very specific-department effect with multi-disciplinary consilience. The learning effect of consilience knowledge between humanistic studies and the engineering domain level in the conducting of projects based on real industrial problems is another area to be explored, as students who participated in multi-disciplinary biomedical and mechanical engineering courses were found to produce better results than mono-disciplinary students [17].

Educators and teaching staff in engineering education, as well as industrial participants, can also gain insights from this conceptual model. It emphasises that the interactions among the various participants for successful project development requires an investment in elaborating a dedicated environment through which to do so. Future research needs to pay attention to the sources and information of the necessary multi-disciplinary domains and the contextual student-centred learning mechanisms in the capstone course that can help to improve the problem-solving process for the capstone project. Thus, educators must not only play an advising and coordinating role [26], but also a supervisory role (rather than facilitative role) in the project process [33].

As mentioned above, this conceptual model will provide fundamental elements and criteria for the development of a tool that will enable all participants to conduct the project effectively. While there are many tools or software programs that would both enable students to manage their projects and help the teaching staff to monitor student progress, while reducing the burden of administrative work, there are unlikely to be many tools enabling support of the interaction among various academic domains, including humanistic studies, as well as the collection, accumulation and utilisation of data, information and consilience knowledge from such interactions among multi-disciplinary domains. Furthermore, a system, which can allow the application of practical knowledge from interactions between students and industrial participants is very important, and needs to provide a benchmarking function to help connect the previous project results and problem-solving methodologies to other students, which has been a bottleneck in the student-centred problem-solving process [18]. Since the development of an integrated and general tool for capstone design in engineering schools based on the conceptual framework is not likely to be easy in reality, it is necessary to gain the support of education policymakers and industry practitioners seeking engineers with a consilience background.

The objective of this article was to formulate a conceptual framework, as an industrial engineering-specific model, which can be used as a basis for guiding the development of a practical tool and for empirical research for future engineering education. As such, the elaboration of targeted research hypotheses and tool development were excluded from this study. However, various avenues of future research have been formulated. Engineering domains other than IE, or country-specific characteristics could also be considered, since these should influence interactions among students, and multi-disciplinary and industrial participants, due to their foundational differences. These items represent an additional future contribution of this research.

ACKNOWLEDGEMENTS

This research was supported by the Basic Science Research Programme through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and future Planning (NRF-2013R1A2A2A03067925).

REFERENCES

1. Geum, Y., Kim, C., Lee, S. and Kim, M-S., Technological convergence of IT and BT: evidence from patent analysis, *ETRI J.*, 34, **3**, 439-449 (2012).
2. Wilson, E.O., *Consilience: the Unity of Knowledge*. New York: Knopf (1998).
3. Kodama, F., Japanese innovation in mechatronics. *Science and Public Police*, 13, **1**, 44-51 (1986).
4. Kodama, F., MOT in transition: from technology fusion to technology-service convergence. *Technovation*, 34, **9**, 505-512 (2014).
5. McWilliam, E., Hearn, G. and Haseman, B., Transdisciplinarity for creative futures: what barriers and opportunities? *Innovations in Educ. and Teaching Inter.*, 45, **3**, 247-253 (2008).
6. National Science and Technology Commission (NSTC), The Basic Development Plan for National Convergence Technology ('09-'13), Seoul: NSTC (2008) (Written in Korean).
7. Kim, J., Jang, Y. and Lee, S., Issues and efforts for technology-humanities convergence: empirical analysis of Korean SMEs. *J. of the Korean Institute of Industrial Engineers*, 40, **5**, 451-461 (2014).
8. Prince, M.J. and Felder, R.M., Inductive teaching and learning methods: definitions, comparisons, and research bases. *J. of Engng. Educ.*, 95, **2**, 123-138 (2006).
9. Lehmann, M., Christensen, P., Du, X. and Thrane, M., Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. *European J. of Engng. Educ.*, 33, **3**, 283-295 (2008).
10. Kolmos, A. and Graaff, E.D., *Process of Changing to PBL*. In: Graaff, E.D. and Kolmos, A. (Eds), Management of Change: Implementation of Problem-based and Project-based Learning in Engineering. Rotterdam: SENSE Publisher, 31-44 (2007).
11. Woods, D.R., *Problem-based Learning: How to Gain the Most from PBL*. Waterdown (1994).
12. Maskell, D.L. and Grabau, P.J., A multidisciplinary cooperative problem-based learning approach to embedded systems design. *IEEE Trans. on Educ.*, 41, **2**, 101-103 (1998).
13. Hadgraft, R., Problem-based learning: a vital step towards a new work environment. *Inter. J. of Engng. Educ.*, 14, **1**, 14-23 (1998).
14. Montero, E. and González, M.J., Student engagement in a structured problem-based approach to learning: a first-year electronic engineering study module on heat transfer. *IEEE Trans. on Educ.*, 52, **2**, 214-221 (2009).
15. Jonassen, D., Instructional design models for well-structured and ill-structured problem solving learning outcomes. *Educational Technol., Research and Develop.*, 45, **1**, 65-94 (1997).

16. Laxman, K., A conceptual framework mapping the application of information search strategies to well and ill-structured problem solving. *Computers & Educ.*, 55, **2**, 513-526 (2010).
17. Hotaling, N., Fasse, B.B., Bost, B.F., Hermann C.D. and Forest, C.R., A quantitative analysis of the effects of a multidisciplinary engineering capstone design course. *J. of Engng. Educ.*, 101, **4**, 630-656 (2012).
18. Graaff, E.D. and Kolmos, A., Characteristics of problem-based learning. *Inter. J. of Engng. Educ.*, 19, **5**, 657-662 (2003).
19. Brown, S.M. and Seider, C.J. (Eds), *Evaluating Corporate Training: Models and Issues*. Springer (1997).
20. Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D. and Leifer, L.J., Engineering design thinking, teaching, and learning. *J. of Engng. Educ.*, 92, **1**, 7-25 (2005).
21. Lave, J. and ScWenger, E., *Situated Learning: Legitimate Peripheral Participation.* New York: Cambridge University Press (1991).
22. Johri, A. and Olds, B.M., Situated engineering learning: bridging engineering education research and the learning science. *J. of Engng. Educ.*, 100, **1**, 151-185 (2011).
23. Howe, S. and Willbarger, J., National survey of engineering capstone design course. *Proc. 2006 American Society for Engng. Educ. Annual Conf. and Exposition* (2006).
24. Korean Institute of Industrial Engineers (KIIE), Creative Engineering Education System and Curriculum Development through Domestic and Foreign Cases and Job Analysis: the Case of Industrial Engineering, Seoul: NRF (2006) (Written in Korean).
25. Hong, S., A model of the curriculum flowchart for industrial engineering. *Review of Engng. Educ. Research*, 16, **6**, 78-86 (2013).
26. Palmer, S. and Hall, W., An evaluation of a project-based learning initiative in engineering education. *European J. of Engng. Educ.*, 36, **4**, 357-365 (2011).
27. Ceschi, M., Silitti, A., Succi, G. and De Panfilis, S., Project management in plan-based and agile companies. *IEEE Software*, 22, **3**, 21–27 (2005).
28. Mann, C. and Maurer, F., A case study on the impact of Scrum on overtime and customer satisfaction. *Proc. Agile Develop. Conf. (ADC'05)*, Denver, USA, 70-79 (2005).
29. Mills, J.E. and Treagust, D.F., Engineering education - is problem-based or project-based learning the answer?, *Australasian J. Engng. Educ.*, 2-16 (2003).
30. Lang, J.D., Cruise, S., McVey, F.D. and McMasters, J., Industry expectations of new engineers: a survey to assist curriculum designers. *J. of Engng. Educ.*, 88, **1**, 43-51 (1999).
31. Jonassen, D., Towards a design theory of problem solving learning outcomes. *Educational Technol., Research and Develop.*, 48, **4**, 63-85 (2000).
32. Accreditation Board for Engineering and Technology (ABET). Criteria for Accrediting Engineering Programs, 2011-2012, ABET (2010).
33. Savin-Badedn, M., *Challenging Models and Perspectives of Problem-based Learning*. In: Graaff, E.D. and Kolmos, A. (Eds), Management of Change: Implementation of Problem-based and Project-based Learning in Engineering. Rotterdam: SENSE Publisher, 9-29 (2007).

BIOGRAPHY

Moon-Soo Kim is a professor in the Department of Industrial and Management Engineering at Hankuk University of Foreign Studies (HUFS) in Korea. He holds a PhD from Seoul National University in Korea. He gained experience as a project manager at the Electronics and Telecommunications Research Institute (ETRI) in Korea prior to joining the University. His research focuses on technology management and its various application fields, as well as recently, engineering education, especially, student-centred learning theory and practices. Dr Kim has published papers in several international journals, such as Technology Analysis and Strategic Management, Omega, ETRI J, Tele. Policy, Telemactics and Informatics, Scientometrics, and Technological Forecasting and Social Change, and others, and also in several domestic journals.