DIVERGENT AND CONVERGENT THINKING PROJECTS IN INTERDISCIPLINARY STUDIES

Chou, Wen Huei,
Department & Graduate School of Digital Media Design, College of Design
National Yunlin University of Science and Technology, Taiwan
cris@yuntech.edu.tw; cristance@gmail.com

ABSTRACT
Several researches have indicated that designers solve problems through synthesis: they design activities to reflect a "way of thinking" and use design thinking as a methodology for the practical, creative resolution of design problems (Buchanan 1992; Cross 1982, 2011; Lawson 1980; McKim 1973; Rowe 1987; Simon 1969). Designers need to think from a "designerly" perspective, and "design thinking" is now used to describe a particular style of innovative problem solving. It generally implies the ability to transform the way products, services, processes, and strategies are developed. This study addresses the innovate quality of design thinking and extends the concept of a "designerly way of thinking" to a project-based course called "Design and Application of Intelligent Electronic Systems,". e use Brown's five characteristics of design thinkers—empathy, integrative thinking, optimism, experimentalism, and collaboration (Brown 2008)—to develop a systematic account of the creative thinking-in-action approach to problem solving for this cross-engineering-and-design project. This study also discusses how the concept-knowledge (C-K) theory facilitates the development of techniques that will better harness the potential for innovation across disciplines. We discover that synthesizing methods can successfully harness both creative and rational activities, so that engineering students who work with design students can more easily adopt a designerly way of thinking and thus solve problems innovatively.

THINK DESIGNERLY AND INTERDISCIPLINARILY

Cross (2001) observes that scientists solve problems through analysis, and designers, through synthesis. Other researchers have indicated that design, by nature, stirs the imagination of a better future and paves the way to obtaining it (Grocott 2005; Rosenburg 2006). The concept of design thinking involves the use of the method, language, material, and practice of design to create knowledge that transforms people's understanding of the possibilities of the discipline (Downton 2003; Fallman 2005; Haseman 2006). The universal thinking approach of designers—"designerly ways"—is recognized as an intuitive and divergent process of problem solving. This manner of thinking also differs from the traditional techno-scientific convergent approach used by engineers (Dym et al, 2005; Beder, 1999; Akay, 2003; Pappas, 2002). The engineering field appears to be ripe for a new educational approach that will integrate the design and engineering disciplines through teaching that runs through both disciplines seamlessly, meets the ever-changing socially responsible requirements, and creates models of reflective practicum (Beder 1999; Green 2001; IME 1985). According to Grasso and Martinelli, the need of the hour is a new kind of engineer who can think broadly across disciplines while considering the human element (Grasso and Martinelli 2007). Akay notes that design consultancies and manufactures now require flexible and adaptable engineers who can operate effectively in global multidisciplinary environments (Akay, 2003).

The expansion of the scope of design brings with it problems that are significantly more complex. An interdisciplinary approach, according to Walker (2011), involves the integration of theory, methods, or knowledge from two or more traditionally distinct disciplines. By its very nature, design represents the human power of conceiving, planning, and creating objects that serve human needs. Samraj and Swales (2000) argue that the effective integration of cross-disciplinary perspectives demands research to obtain grounding on the specific problems faced in the each field. Norgaard and Sharachchandra (2005) observe that although scientists come together in cross-disciplinary teams based on some shared interest, the outcomes do not necessarily translate into an effective research plan with clear links between the various disciplines. Although the need for connections on a vertical dimension is undoubtedly important, it is also necessary to conduct an analysis using an interdisciplinary approach in this specific context, as it can provide useful insights into the problems encountered by researchers in their disciplinary training and conditioning. Many researchers have argued that creativity is of utmost importance in engineering, as it endows practitioners with the insight and discipline necessary to seek out and address problems in the field's various disciplines (Ghosh 1993; Pappas

2002). However, many engineering institutions continue to focus on engineering science and train potential engineers in technological task completion. As a result, students do not have the opportunity to develop design aptitude or creativity (Dym 2005; Beder 1997; Akay 2003; de Vere 2009).

Thus far, the design activities in an engineering process are concurred to solve ill-defined problems. The process requires the synthesis of problem framing and solving; a creative, divergent, and adaptable approach; and less fixation on prior solutions (Cross 2006). Schön viewed the problem-solving elements of design research as "situated activity" and considered design in terms of "reflective activity" and related notions, including "reflective practice," "reflection-in-action," and "knowing-in-action" (Schön 1983). To be able to explore and develop their ability in problem framing, engineering design students have to be capable of divergent thinking, critical reflection, and creativity. These aspects have conventionally been characterized as "ill-defined" (Simon 1969) or "wicked" problems (Rittel and Webber 1972; Dunne and Martin 2006) fraught with "figural complexity" (Schön 1990).

The traditional methods of reasoning used by engineers are no longer sufficient because the current situation in the field is radically different from classical optimization and modeling (Hatchuel and Weil 2011). Such is the situation in the field of design as well; the direction of contemporary design research has already been transformed from one based on the production of artifacts to one that is focused on the integration of varied knowledge and fields at different stages. However, designers in the knowledge domain encounter multifarious problems. In order to work with experts from diverse fields, they have to adopt more systematic models that give due consideration to both rationality and innovation. In this study, we examined an interdisciplinary project by using a project-based study that develops a teaching process implemented on the basis of' Brown's five characteristics for design thinkers (2008) and Schön's design-thinking process (Schön 1983), to observe how design and engineer students co-work and react in the process of problem solving of interdisciplinary context. After the course was completed, we analyze means of developing and delivering a multidisciplinary design-thinking project—in this case, for engineering and design students—by referring to the concept-knowledge (C-K) theory and employing reflection-in-action analysis.

CONCEPT-KNOWLEDGE THEORY

Brown (2008) puts forth five characteristics for design thinkers: empathy, integrative thinking, optimism, experimentalism, and collaboration. Design thinkers need empathy to adopt a people-first approach with which to imagine the world from different perspectives; integrative thinking, to create novel solutions for great innovations; optimism, in the face of many challenges, for better solutions; experimentalism, in order to move from taking small incremental steps to creating breakthrough innovations; and collaboration, in order to work with others from different disciplines. Brown also states that the design-thinking process can best be represented as a "system of spaces." He said that there are three spaces—inspiration, ideation, and implementation. Inspiration refers to the opportunity or motivation to search for solutions to a problem; ideation, the process of generating, developing, and testing new ideas; and implementation, the execution of ideas from the project stage to people's lives (Brown 2010). Brown's characteristics and spaces serve as important guidelines for creating a valuable framework by which to consider the concept of design from the perspectives of problem acknowledgement and definition to the final problem resolution (Howard and Davis 2011). However, when focusing on teaching and learning activities in project-based design for engineering students, Brown's system appears to depart from the engineering and interdisciplinary domain. His system omits some expert knowledge on teaching and learning elements for engineering and other students. Therefore, in the present study, we apply the C-K theory to Brown's system in order to enhance the integrity of the course design for engineering students and the relevant interdisciplinary teaching situations.

The C-K theory is a unified design theory introduced by Hatchuel and Weil (2003). It is at once a theory of design and a theory of rationality in design, and seeks to describe certain design activities rationally (Hatchuel and Weil 2003; Kazakci and Tsoukias 2004). Design, then, is defined as "the interaction of concept and knowledge spaces." The C-K theory rests on the assumption that design can be modeled in terms of an interplay between two interdependent spaces: concepts and knowledge (Hatchuel and Weil 2003, 2009). Since design is a dynamic mapping process between required functions and selected structures, the C-K theory can be considered a research field and teaching area (Hatchuel and Weil 2009). Schön's (1983) concepts of reflective practice, reflection-in-action, and knowing-in-action are presented in the dynamic mapping process between the interdependent spaces of concept and knowledge. The C-K theory is mainly used to investigate the divergent and convergent design thinking processes of engineering students. For an interdisciplinary learning approach targeting both engineering and design students, it is necessary to obtain a significant and designerly solution to the problem. Moreover, the aim is to enable students from both fields to adopt a designerly way of thinking and solve their problems innovatively.

In much of the literature, the C-K theory is summarized as a theory that teaches divergent thinking (DT) and convergent thinking (CT) in a collaborative, controlled manner. Divergent thinking comes into play in situations where new, original worlds have to be created, and it requires the ability to break existing generative rules and create alternative realities. On the other hand, convergent thinking equips students with the ability to use knowledge to activate expertise, transform it into usable skills, and link existing abstract engineering science models (Brereton 1999; Boden 1990; Dym et al. 2005; Loch et al. 2006). Hatchuel, Masson, and Weil (2011) state that the C-K theory can serve as a supportive framework to improve PBL; it can improve students' critical abilities, allowing them to give due thought to the main issues in innovative design education. Additionally, in an interdisciplinary project that falls within the C-K theory structure, students tend to have different tasks when focusing on both design and engineering perspectives (Eris 2004; Dym et al. 2005; Hatchuel, Masson, and Weil 2011; von Hippel 2001; Magnusson 2003; Pahl and Beitz 2006; Finke 1990; Ward et al. 1999; Shah et al. 2003; Plety and Cremet 2007).

According to Hatchuel and Weil (2002, 2009), interactions between the concept and knowledge spaces match the particular cognitive efforts that designers deploy during the design process. The C-K theory proposes to model them through the four operators: K→C, C→K, C→C, and K→K.

• K→C involves the generation of tentative concepts by adding new attributes to an already partitioned existing concept. This operator adds or subtracts a property from the K-space as a new attribute of a concept in the C-space. As it allows the partition of an initial concept, this operator expands the C-space with elements from the K-space. From a managerial perspective, it models a step of the description of a design path.

• C→K involves the search of attributes in K that can be used to partition C; then, it must be confirmed whether the newly generated C is a concept or knowledge. This operator seeks to add or subtract properties in the K-space in order to reach propositions with a logical status. When it succeeds, it creates a "conjunction" which stops the design process. When it does not succeed, the operator expands knowledge through the adjunction of concepts, which leads designers to the knowledge acquisition process.

• C→C implies a graph operator in space C (paths, chains). This operator relies on the classical rules in set theory that control partition or inclusion. From a managerial perspective, a partition can be either restrictive or expansive. A restrictive partition reduces the space of possibilities without changing the definition or attributes of the object to be designed. An expansive partition modifies the identity of the initial design object by adding unexpected attributes to the initial concept. It is precisely these expansions that make breakthrough innovations, including surprises, possible.

• K→K is the reasoning of one type of knowledge to another (classification, deduction, abduction, etc.). This operator relies on the classical rules of logic and propositional calculus that allow the K-space to have self-expansion; e.g., proving new theorems. For managers, K→K operations describe designers' actions to increase the reliability of propositions in K.

The C-K theory provides a consistent and formal account of creativity and learning during the design process, and reflects a thinking process between DT and CT. Kruger and Cross (2006) observe that designers focus closely on the problem at hand and strictly use only the information and knowledge that is needed to solve that problem. In the interdisciplinary approach, the emphasis lies in defining the problem and finding a quick solution. Hence, Dym et al. (2005) stated that the teaching of innovative design in a project-based program requires a better understanding of design thinking. The theory of design thinking is extremely useful because it can be taught and learned in a relatively short period using controllable processes, with evaluations and exercises to improve creative efficiency. However, considering the sheer variety of cross disciplines in existence, the problem is how to develop a design-based project to harness existing knowledge and integrate DT and CT processes to fulfill educational goals.

In this research, we use the C-K theory in an interdisciplinary project-based course called "Design and Application of Intelligent Electronic Systems." The participants comprise third-year students from the electrical engineering and digital media design departments of the National Yunlin University of Science and Technology in Taiwan. The purpose of the course program is to allow integration and cooperation in two domains. The aims of this research are to explore how engineers can acquire the capacity for innovative design reasoning (McMahon et al. 2003), how designers can obtain rational reasoning knowledge (Eris 2003, 2004), and how students can gain critical abilities and give due consideration to the main issues in innovative design education. Moreover, when investigating the characteristic of reflection-in-action, which is reflected in the C-K spaces, on behalf of addressing a teaching reference for cross-disciplinary courses, it helps to teach creative design in project-based activities, especially in the engineering and design domains. The rationale behind recruiting students from two departments was that the digital media design students had only a very basic background in programming, while the electrical engineering students were used to project-based courses that required some experience in innovation.

METHOD AND CASE INTRODUCTION:

Participant observation has been used in qualitative research in a variety of disciplines for collecting data about people, processes, and cultures (Preissle, & Grant, 2004); it helps deepen researchers' understanding of the context and phenomenon under study, allowing them to discover, through immersion and participation, the 'hows' and 'whys' of

human behaviour in a particular context. The researcher is required to engage in a variety of activities and pay attention to multiple considerations (DeWALT & DeWALT, 2002). For many years, it has been applied in both anthropological and sociological research. Recent years have witnessed an increase in the number of qualitative studies in the field of education that include participant observation as a data-collection tool (Kawulich, 2005), including establishing rapport with those being observed, checking for nonverbal expression of feelings, selecting key informants, grasping how participants communicate with each other, establishing processes for conducting observations, deciding what to observe and when, keeping field notes, and writing up one's findings (Whyte, 1979, SCHMUCK, 1997). During the participant observation process, the observers must maintain a certain degree of openness while conducting the research, and redefine and modify the research questions on the basis of their discoveries and observations. Participant observation is a key strategy used to gain understanding of aspects of human conditions that are otherwise difficult to academically examine. Data are collected primarily through direct observation and experience (Jorgensen, 1999).
In the present study, we used participant observation to investigate how students from different knowledge backgrounds cooperate in the design process, and how they 'act-in-reaction' in the process of learning and delivering. We document mainly the course process, which includes teaching, group discussion, presentation, and feedback. Different kinds of data are collected for analysis—videos, photographs, conversation records, and all drawings and drafts produced during the process. We focus on the analysis of such interplays to 'to improve our recognition of design activities. Similarly, the recognition of groups and analysis of their structures are necessary for group activity detection, so the observers were allowed to interview students informally at the same time at which they were conducted participant observation, when they need more detailed descriptions and explanations to understand the context. Therefore, we used two models to analyze the data. In the first model, we investigate what kind of backgrounds do participants bring to the group and, in the context of these backgrounds, how they react to the introduction of a new concept or new knowledge, and the divergent and convergent thinking they exhibited during the four processes of this project. We categorize students' discussing and thinking activities into mind maps for the four processes. We particularly focus on the concept-generating phase, wherein ideas are generated, and how students' design and engineering skills are dispersed and integrated. In the second analysis, we investigate how the structure of the C-K operators (K→C, C→K, C→C, and K→K) is formed in a system involving three systematic spaces, and analyze how action and reaction occur between these spaces.

The course under investigation, Design and Application of Intelligent Electronic Systems, is developed for both the electrical engineering and digital media design departments. The course is taught by four professors, two with electrical engineering backgrounds, and two from the media design field. Forty-seven students enrolled in the course: 21 from design school, 25 from engineering, and one from architecture design. The aim of the newly amended course was to establish an interdisciplinary and integrative setting for students from all departments, enabling them to implement existing knowledge of the design process and gain new knowledge as well.

All 47 students attended class together; they were grouped into teams of two, one member from each department. There were three extra engineering students, and each was assigned to an already "complete" team. Thus, three of the teams had three members.

The six-week course analyzed in this study was the first project for the semester (Table 1). The teaching goals were twofold: design and technique. To achieve the design goal, students had to create ample and interesting interaction by incorporating functions into their own old toys using micro controls. To achieve the technique target, students had to learn micro controls and system design. The project consisted of teaching phases that were decided on the basis of Brown's (2008, 2010) five characteristics: empathy (E), integrative thinking (I), optimism (O), experimentalism (EX), collaboration (CO) of design thinkers; and the system of spaces: inspiration (A), ideation (B), and implementation (C). All activities were divided into 10 phases, which took into account all the above-mentioned criteria: (1) visual thinking warm-up exercise, (2) mind map for toys, (3) group sharing, (4) team building and project explanation, (5) introduction of micro controls, (6) concept development and converging, (7) comments and discussion, (8) project execution, (9) design-technical suggestions and instruction, and (10) final presentation and demonstration (Table 2). Below is a detailed description of the phases and their time distribution.

1. Warm-up exercise

   This activity was designed to inspire students to think visually, and help them shake off the conventional associate thinking. It was also important in teaching students to think and draw spontaneously.

2. Mind map for toys

   Students were asked to bring one or two of their old toys to class. Each had to draw an individual mind map from emotional, sensational, interactive, reminiscent, and material aspects to describe the toy(s) (Fig. 1). They were also encouraged to develop their own categories when drawing their mind maps.

3. Group sharing

   Since this was a big class, and it was vital that all students be able to share, they were divided into eight groups.

Thus, each student had enough time to share and discuss their toy(s) and mind map with their groups (Fig. 2).

4. Team building and project explanation

   Each student was asked to find a partner from another department. Since there were 25 students from engineering but only 22 from design, three engineering students could not be paired off. Each "extra" was added to a team, so that three of the teams had three members. Students were also taught how to develop their projects from both the technical and design perspectives, and what to bring for their final achievements (Fig. 3).

5. Introduction of micro controls

   This phase was taught by one engineering professor alone. In the first week, the Arduino hardware platform and its software development environment were introduced; the students learned the basic concepts of digital input and output. Finally, they were asked to finish a laboratory experiment that included LED controls, a 7-segment LED, and a button. During the second week, the students learned the Arduino program language, followed by communication with a PC via the RS-232 interface, lighting sensor, and servo motor control. In the third week, the students were introduced to the pressure sensor, infrared sensor for distance measurement, and 3-magnetometer.

6. Concept development and converging

   Students had three weeks to develop and retrieve their designs while simultaneously learning how to use micro controls. At the end, they were asked to put down their concepts on three 2K pages (Fig. 4).

7. Comments and discussion

   Students were divided into two groups, A and B, each of which had one week for comments and discussion (Figs. 5 and 6).

8. Project execution

   Students were encouraged to develop their projects, giving due consideration to the design concepts and techniques taught in phases 1-7.

9. Design-technical suggestions and instruction

   All the students and professors joined a private group on Facebook; we used this space as a virtual classroom to exchange ideas and hold discussions, along with face-to-face discussion (Fig. 7).

10. Final presentation and demonstration

    In the sixth week, the students presented their final projects (Figs. 8 and 9).

Table 1: Project timeline

Time / Phase		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
1	In class	30 min					
2	In class	30 min					
3	In class	90 min					
4	In class	30 min					
5	In class		3 h	3 h	3 h (group A)	3 h (group B)	
	Homework		■	■	■	■	
6	Homework	■	■	■	■		
7	In class				3 h (group B)	3 h (group A)	
	Homework			■	■	■	
8	Homework				■	■	■
9	Virtual discussion				■	■	■
10	In class						3 h

Table 2: Project teaching plan, with comparisons between design characteristics and system of spaces

Phase	Characters	Systematic spaces	Activities
1		A	warm-up exercise
2	E	A	mind map for toys
3	I	A	group sharing
4	I	A	team building and project explanation
5		B	introduction of micro controls
6	I; O	B	concept development and converging
7	I; O	B	comments and discussion
8	EX; CO	C	project execution
9		C	design-technical suggestions and instruction
10			final presentation and demonstration

Designer characteristics: empathy (E); integrative thinking (I); optimism (O); experimentalism (EX); collaboration (CO).
Systematic spaces: inspiration (A); ideation (B); implementation (C).

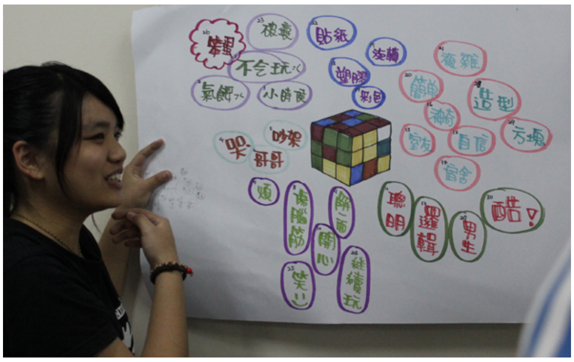


Fig. 1 Mind map for toys

Fig. 2 Group sharing

Fig. 3 Team building and project explanation

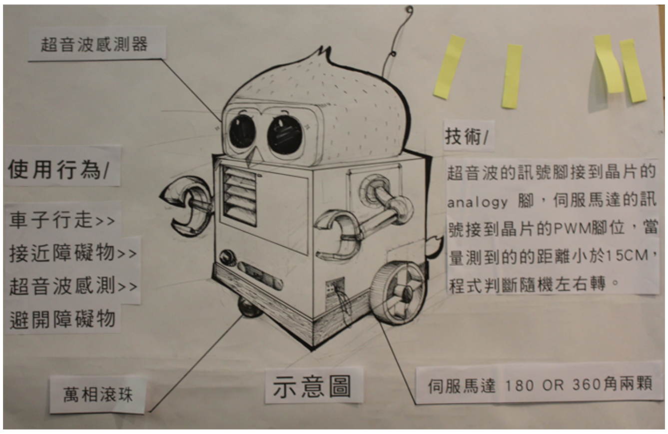


Fig. 4 Concept development and converging-1

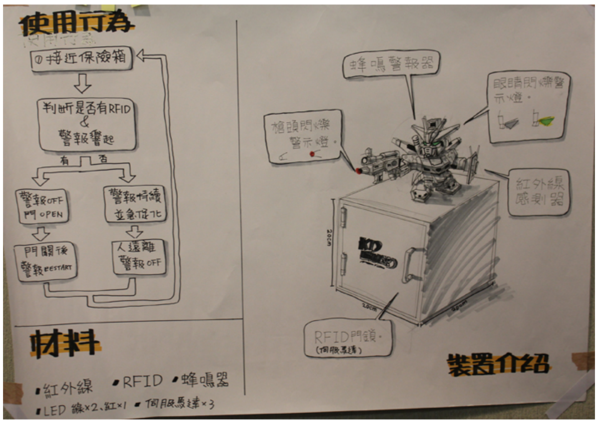


Fig. 5 Concept development and converging-2

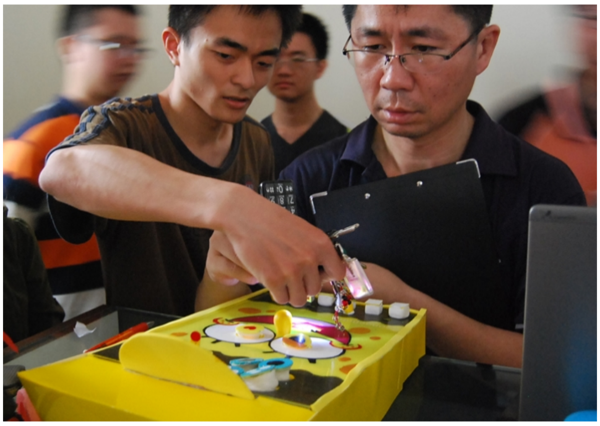


Fig. 6 Comments and discussion

Fig. 7 Concept sharing in a group

Fig.8 Final presentation and demonstration – Donut bear project

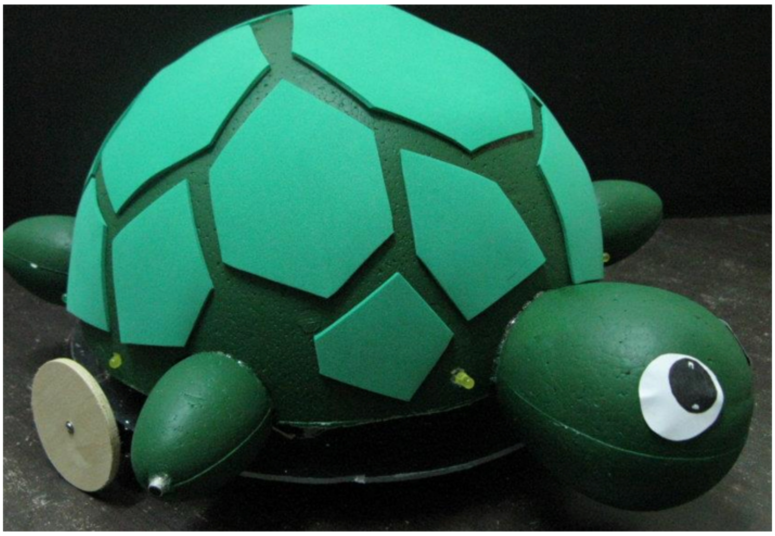


Fig. 9 Final presentation and demonstration – Spy turtle project

CASE ANALYSIS

The research was subjected to a two-step analysis. The first step was an addition to the extended analysis of the C-K theory, which teaches divergent and convergent thinking in a collaborative, controlled manner. We observed a synergy model with a reference value for the interdisciplinary project-based design (Fig. 10).

The serial models focus on project exploration and cooperation, and mainly demonstrate how concepts and ideas are diverged and converged interdisciplinarily during the design activities. The first phase shows how "brainstorming" brings together multidimensional concepts. The second phase, "converging ideas," involves condensing and reconstructing. Here, the students have to make compromises by practicing restraint in their personal design plans to give way to consensus. The third phase, "ideation," implies the development of deeper concepts and the conveyance of knowledge from both sides to verify the entire scope of the project. The final phase, "implementation," not only involves a division of labor but is also a phase where close attention is paid to cross-disciplinary adjustment and comprehension. This working diagram can help educators or project managers set their own working models.

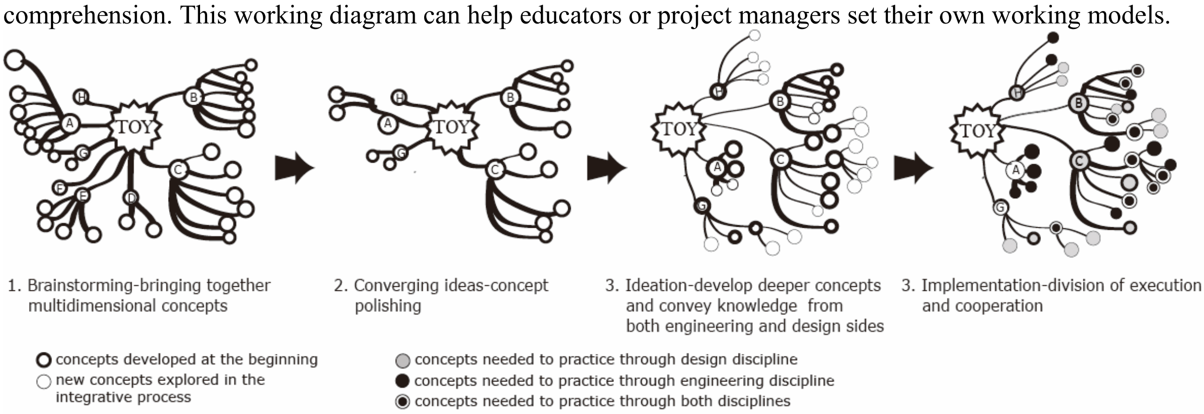


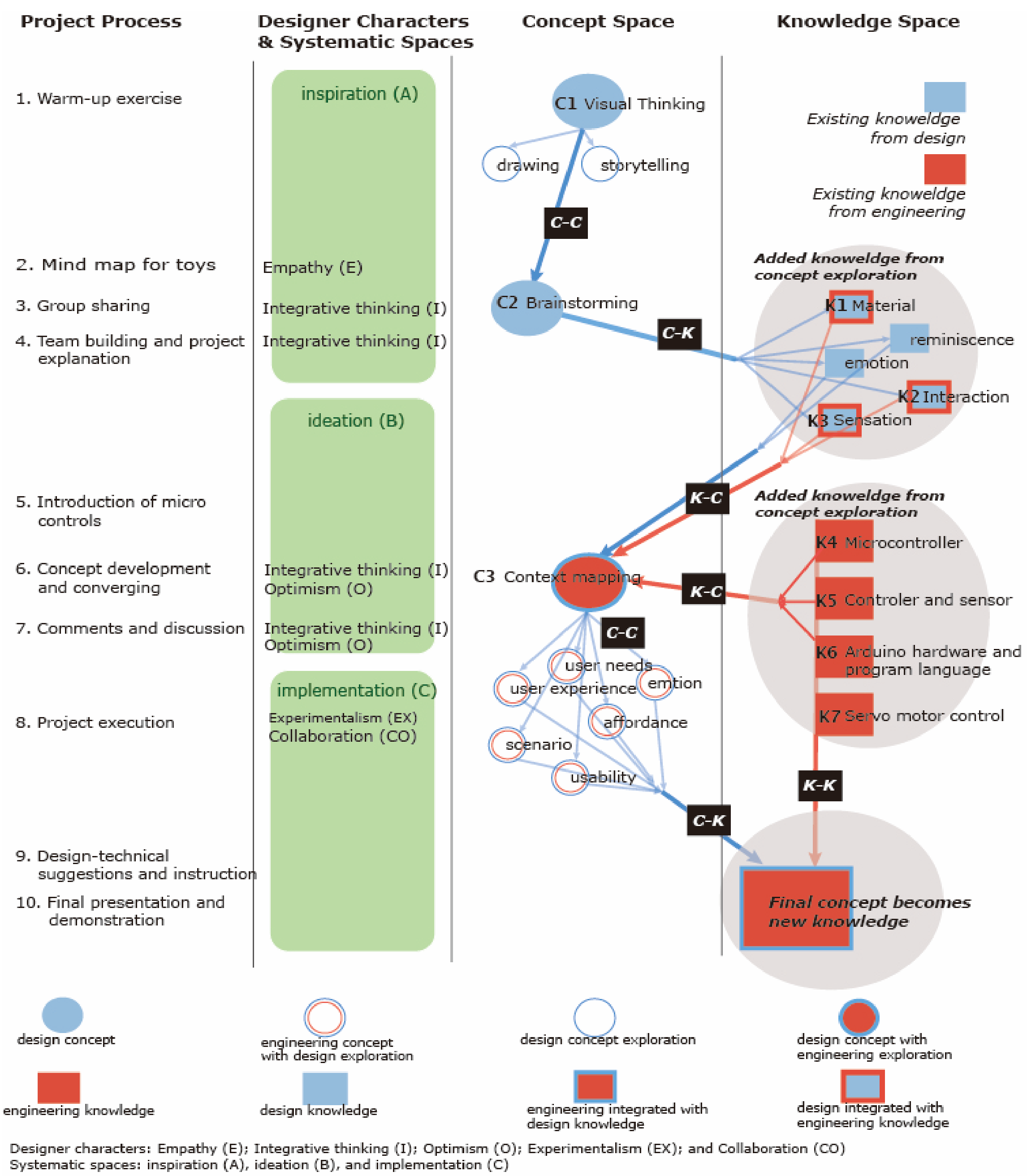
Fig. 10 Synergy of divergent thinking (DT) and convergent thinking (CT) processes

In the second step, we applied the system of three systematic spaces and the C-K theory combinations operators (K→C, C→K, C→C, and K→K) in analyzing how reflection-in-action can be divided with the concept-knowledge theory, and if all the teaching phases have fulfilled the goal of the project. A diagram extracted from this case is illustrated in Figure 10. The first column on the left lists the 10 phases designed for the teaching process, and the second column is integrated from Table 1 for referring to the status of the analysis. The third and fourth columns are the concept and knowledge spaces, which are meant to seek to the design activities rationally. After comparing the results with the dynamics diagram of the original C-K theory combination operators from Hatchuel et al. (1999, 2004), we found several points of concern for both the cross-disciplinary situation and the design thinking teaching process. However, we divided the four operators into eight categories to clarify the action and reflection in the design-thinking interrelated activities within engineering and design disciplines. The eight categories are design concept, engineering knowledge, design knowledge, design concept exploration, engineering concept with design exploration, engineering integrated with design knowledge, design concept with engineering exploration, and design integrated with engineering knowledge.

Fig. 11 Case study of reflection-in-action

1. With regard to the systematic design thinking process, more existing knowledge is fostered in the inspiration space, where the students from both backgrounds need to cooperate with each other to firmly grasp the concept, knowledge, and design limitations of the topic of discussion. Although the problems faced by students from different departments may be the same, eventually, what they take with them from the course and the knowledge they acquire are very different. For example, if the topic under discussion in the knowledge space is "material," the design student will be concerned about the taction, texture, and sensation of the material. On the other hand, the engineering student will consider the component, weight, toleration, and assembly possibilities of the material.
2. In reality, the cross-discipline learning process takes on a more complicated C-K working structure compared to a solo discipline and initiates the C-K theory.
3. Normally, the design and engineering fields assume their own paths for concept and knowledge space and reflective action. However, because this project was a cross-discipline concern, the students' concept and knowledge paths were intertwined, and they had to solve phasic problems together before moving on to the next task.

4. The concept and knowledge status can be planned in projects to ensure that certain specifications and knowledge are imbibed by the students. If not, the reflection-in-action cognitions reflected between concept-knowledge spaces are spontaneously contingent on the dynamic exporting processes.
5. The reflection-in-action cognitions reflected between concept-knowledge spaces are not linear. Therefore, the four interdependent operators of the concept-knowledge theory (K→C, C→K, C→C, and K→K) can occur simultaneously. These reflective paths are not fixed; they depend on the actions and reflections of students from both disciplines.
6. Kazakci (2006) purports to extend the concept-knowledge design theory by taking into account the environment (E). He states that it is of particular importance to designers to provide a situated context. However, according to our investigation and analysis, we believe that the situated context is created in between the concept and knowledge spaces. Further, the environment factor is likely to be subsumed to these two spaces.
7. To ensure that learning objectives are attained at all stages of this multidisciplinary project, the learning processes need to be planned properly, and integrity of discussion should be allowed for both solo disciplinary and interdisciplinary fields. Conversely, some amount of flexibility should also be allowed in case of irregular innovation and inspiration.



CONCLUSIONS

In this study, we aimed to discover how engineering and design students can accomplish design thinking in an interdisciplinary project through the use of synthesizing methods. We hoped that through this project-based case study, students would acquire skills related to both innovation and knowledge in two expert fields—design and engineering. Teaching a project-based program means providing students with procedural knowledge (Koedinger and Corbett 2006) and planning particular contextual tasks for them. Figures 10 and 11 show how the integration and evolution models for various learning theories and types of knowledge can be used in interdisciplinary project-based teaching. Design thinking is a schematized approach, in which divergent thinking becomes convergent, and new knowledge is created. In order to teach design thinking in interdisciplinary fields, clear tasks should be set for several learning stages, and instructive self-reflection and steps of action research are needed to intensify the spirited interaction between concept and knowledge.

According to Hatchuel et al. (2011), design is both a dynamic mapping process and a generation process of new objects, involving the construction of mental representations and external artifacts (Liikkanen and Laakso 2012). If an educator from any discipline attempts to employ design thinking as an apparatus for activating present discipline and knowledge, it is necessary for that educator to develop an elaboration likelihood context that students can experience and explore, and to facilitate portals wherein students can explore, analyze, and find solutions. In the end, the aim of this research is not to establish a paragon for interdisciplinary teaching projects; rather, it is to build a potential referencing model for teaching design thinking in interdisciplinary fields. The model will be considered as a concept-and-knowledge, action-in-reflection design contextual process to fulfill the needs of an interdisciplinary design project. Another goal is to enable students from both fields to adopt a designerly way of thinking and solve their problems innovatively. However, this research postulates the case study as an interdisciplinary project; although the C-K theory is mainly used to investigate the design thinking processes in engineering students, we did not particularly distinguish between engineering and design students. They were asked to work out all phases together, rather than discuss how the concept and knowledge activities could be designed upon the various disciplines engaged in the situation.

ACKNOWLEDGEMENTS

This material is based on the course supported by Intelligence electronic (IE) interdisciplinary curriculum plan in National Yunlin University of Science & Technology under the grants from Ministry of Education in Taiwan. Thanks of faculties, Hwang, Chorng-Sii, Hung, Chung-Wen, Shiau, Yeu-Horng and Chang, Teng-wen, who'd participated in this course. Any finding and conclusions or recommendations expressed in this paper are those of the author and do not necessarily reflect those of the course project.

REFERENCES

Akay, A. (2003). The renaissance engineer: educating engineers in a post-9/11 world. *European Journal of Engineering Education*, 28(2), pp. 145-150.
Alexander, C. (1964). Notes on the Synthesis of Form. Cambridge, MA: Harvard University Press.
Argyris, C. and Schön, D.A. (1996). Organizational Learning II. Reading, MA: Addison–Wesley.
Beder, S. (1997). The Social Role of the New Engineer. Melbourne: Macmillan.
Beder, S. (1999). Beyond technicalities: Expanding engineering thinking. *Journal of Professional Issues in Engineering*, 125 (1), pp. 12-18.
Boden, M. (1990). The Creative Mind. London: George Weidenfeld and Nicolson Ltd.
Brereton, M. (1999). The role of hardware in learning engineering fundamentals: an empirical study of engineering design and product analysis activity. PhD Thesis. Stanford University.
Brown, T., and Wyatt, J. (2010). Design thinking for social innovation. *Stanford Social Innovation Review*, Winter, pp. 30-35.
Brown, T. (2008). Design Thinking. *Harvard Business Review*, June 2008, 84-95.
Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, Vol. 8(2), pp. 5-21.
Cropley, A. (2006). In praise of convergent thinking. *Creativity Research Journal*, 18(3), pp. 391-404.
Cross, N. (1982). Designerly ways of knowing." *Design Studies,* Vol. 3(4), pp. 221-27.
Cross, N. (1999). "Design research: a disciplined conversation." *Design Issues*, Vol. 15(2), pp. 5-10.
Cross, N. (2001). Designerly ways of knowing: design discipline versus design science. *Design Issues*, 17(3), pp. 49-55.
Cross, N. (2011). Design Thinking: Understanding How Designers Think and Work. Oxford and New York: Berg.
de Vere, I. (2009). Developing Creative Engineers: a Design Approach to Engineering Education, Proceedings of 'Creating a Better World', The 11th International Conference on Engineering and Product Design Education (E&PDE 2009), Brighton, United Kingdom, 10-11 September 2009 (http://swinburne.academia.edu/IandeVere/Papers/278396/Developing_Creative_Engineers_a_Design_Approach_to_Engineering_Education).
de Vere, I., Melles, G., and Kapoor, A. (2010). Product Design Engineering: Interdisciplinary Pedagogy Integrating Engineering Science with 'Designerly Ways', Connected 2010 – 2nd International Conference on Design Education 28 June-1 July 2010, University of New South Wales, Sydney, Australia.
DeWalt, Kathleen M. & DeWalt, Billie R. (2002). *Participant observation: a guide for fieldworker*s.Walnut Creek, CA: AltaMira Press.
Downton, P. (2003). Design Research. Melbourne: RMIT University Press.
Dym, C.A. (1999). Learning engineering: Design, languages and experiences. *Journal of Engineering Education*, 1999, 88(2), pp. 145-148.
Dym, C.A., Agogino, A.M., Eris, O., Frey, D.D., and Leifer, L.J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, January 2005, pp. 103-119.
Dunne, D., and Martin, R. (2006). Design thinking and how it will change management education: an interview and discussion. *Academy of Management Learning and Education*, 5(4), pp. 512-523.
Eris, O. (2003). Asking Generative Questions: A Fundamental Cognitive Mechanism in Design Thinking. Proc. Int. Conf. Engineering Design, ICED'03, Stockholm.
Eris, O. (2004). Effective inquiry for innovative engineering design. Boston: Kluwer Academic.
Fallman, D. (2005). 'Why Research-oriented Design Isn't Design-oriented Research'. Nordic Design Research

Conference 'In The Making', Copenhagen, Denmark, May 29-31, 2005.
Finke, R.A. (1990). Creative Imagery: Discoveries and Inventions in Visualization. Hillsdale, NJ: Erlbaum.
Ghosh, S. (1993). An exercise in inducing creativity in undergraduate engineering students through challenging examinations and open-ended design problems. *IEEE Transactions on Education*, 36, pp. 113-119.
Grant, D. (1979). "Design methodology and design methods." *Design Methods and Theories*, Vol. 13(1), pp. 46-47.
Grasso, D., and Martinelli, D. (2007). Holistic engineering. *The Chronicle Review*, 53, B8.
Green, G. (2001). Redefining engineering education: the reflective practice of product design engineering. *International Journal of Engineering Education*, 17 (1), pp. 3-9. ISSN 0949-149X.
Haseman, B. (2006). A manifesto for performative research. *Media International Australia Incorporating Culture and Policy*, Vol. 118, pp. 98-106.
Hatchuel, A., and Weil, B. (2003). A New Approach of Innovative Design: An Introduction to C-K Theory (http:/ / www. cgs. ensmp. fr/ design/docs/ HatchuelWeil2003CKICED. pdf). Proceedings of the International Conference on Engineering Design (ICED'03), Stockholm, Sweden, pp. 109-124.
Hatchuel, A., Le Masson, P., and Weil B. (2004). C-K Theory in Practice: Lessons from Industrial Applications. 8th International Design Conference, Design 2004, (Ed., D. Marjanovic), Dubrovnik, Croatia.
Hatchuel, A., and Weil, B. (2007). Design as Forcing: Deepening the Foundations of C-K Theory. Proc. Int. Conf. Engineering Design, ICED'07, p. 12, Paris.
Hatchuel, A., Le Masson, P., and Weil, B. (2008). Studying creative design: the contribution of C-K theory. Proc. Conf. Studying Design Creativity: Design Science, Computer Science, Cognitive Science and Neuroscience Approaches, Aix-en-Provence, France, March 10-11.
Hatchuel, A., and Weil, B. (2009). C-K design theory: An advanced formulation (http:/ / www. springerlink. com/ content/ u073n68w34548501/), Research in Engineering Design, 19(4), pp. 181-192.
Hatchuel, A., Le Masson, P., and Weil, B. (2011). Teaching innovative design reasoning: How concept-knowledge theory can help overcome fixation effects, Artificial Intelligence for Engineering Design Analysis and Manufacturing (2011) Vol. 25(01), pp. 77-92.
Howard, Z., and Davis, K. (2011). From solving puzzles to designing solutions: Integrating design thinking into evidence based practice. *JEvidence Based Library and Information Practice*, Vol. 6(4), pp. 15-21.
IME (1985). The formation of mechanical engineers: Present and future needs (the grant report). Institution of Mechanical Engineers.
Kawulich, Barbara B. (2005). Participant Observation as a Data Collection Method. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *6*(2), Art. 43, http://nbnresolving. de/urn:nbn:de:0114-fqs0502430.
Kazakci, A. and A. Tsoukias (2004). *Extending the C-K design theory to provide theoretical background for situated design agents*. Proceedings of International Design Conference - DESIGN 2004, (Ed, D. Marjanovic), Dubrovnik, Croatia. 1, pp. 45-52.
Jacques, R., and Powell, J. (Eds.) (1981). Design: Science: Method. Westbury House, Guildford.
Jorgensen, D. (1989), Participant observation: A methodology for human studies. Applied Social Research Series, Vol 15. Newbury Park: Sage Publication.
Lawson, B. (1980). How Designers Think: The Design Process Demystified. London: Architectural.
Laakso, M. L., Liikkanen, L. A., & Factory, A. D. (2012). Dubious Role of Formal Creativity Techniques in Professional Design. In *International Conference on Design Creativity,* Glasgow, UK.
Loch, C.L., De Meyer, A., and Pich, M.T. (2006). Managing the Unknown. Hoboken, NJ: Wiley.
Magnusson, P. (2003). Managing user involvement for service innovation, findings from end-user telecom services innovation. *Journal of Service Research*, 6(2), pp. 111-124.
McKim, R. (1973). Experiences in Visual Thinking. Brooks: Cole Publishing Co.
McMahon, C.A., Ion, B., and Hamilton, P. (2003). Sharing Experience in Engineering Design Education: Historical Background and Future Plans. Proc. Int. Conf. Engineering Design, ICED'03, p. 10, Stockholm.
Pahl, G., and Beitz, W. (2006). Engineering Design: A Systematic Approach. Berlin: Springer.
Pappas, E. (2002). *Creative Problem Solving in Engineering Design*. Proceedings of the 2002 American Society of Engineering Education (ASEE) Southeastern Section Meeting, University of Florida, Gainesville.
Plety, R., and Cremet, C. (2007). Pédagogie de l'innovation. Unpublished manuscript.
Preissle, J., & Grant, L. (2004). Fieldwork traditions: Ethnography and participant observation. In K. deMarrais & S. D. Lapan (Eds.), Foundations for Research: Methods of Inquiry in Education and Social Sciences (pp. 161 - 180). Mahwah, NJ and London: Lawrence Erlbaum Associates.
Ritchey, T. (1991). Analysis and Synthesis: On Scientific Method - Based on a Study by Bernhard Riemann. *Systems Research,* Vol. 8(4), pp. 21-41.
Rittel, H.W.J., and Webber, M.M. (1972). Dilemmas in a General Theory of Planning, p. 22. Berkeley, CA: University of California at Berkeley.
Rowe, P.G. (1987). Design Thinking. Cambridge: The MIT Press.
Schensul, Stephen L.; Schensul, Jean J. & LeCompte, Margaret D. (1999). *Essential ethnographic methods:*

observations, interviews, and questionnaires (Book 2 in Ethnographer's Toolkit). Walnut Creek, CA: AltaMira Press.
Schön, D.A. (1983). The Reflective Practitioner: How Professionals Think in Action. New York: Basic Books.
Schön, D. A., and Wiggins, G. (1992). Kinds of seeing and their function in designing. *Design Studies,* 13, pp. 135-156.
Simon, H. (1969). The Sciences of the Artificial. Cambridge: MIT Press.
Sutton, R.I., and Hargadon, A. (1996). Brainstorming groups in context: effectiveness in a product design firm. *Administrative Science Quarterly*, 41(4), pp. 685-718.
von Hippel, E. (2001). Perspective: User toolkits for innovation. *Journal of Product Innovation Management*, 18, pp. 247-257.
Walker, G. (2011). The role for ‘community’in carbon governance. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(5), 777-782.
Ward, T.B., Smith, S.M., and Finke, R.A. (1999). Creative cognition. In Handbook of Creativity (Sternberg, R.J., Ed.), pp. 189-212. Cambridge: Cambridge University Press.
Whyte, William F. (February, 1979). On making the most of participant observation. *The American Sociologist, 14*, pp.56-66.