DESIGN THINKING IN DIFFERENT DISCIPLINES
COMPARING “DESIGN THINKING” PATTERNS BETWEEN INDUSTRIAL
AND ENGINEERING DESIGN STUDENTS AND ITS IMPLICATION ON THE
DESIGNING PROCESS

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1. INTRODUCTION
Design thinking is usually considered as a style of thinking which underlines all design domains/disciplines, and is
complementary to scientific thinking and other non-design thinking (Archer et al., 2005; Cross, 2008a; Owen,
2006). In the context of tertiary education, design thinking has been implemented in many design programs and
curricula with the purpose of educating designerly thinkers (Meinel & Leifer, 2010; Oxman, 1999). These
programs and curricula often model design thinking as a human-centered methodology (Kelley & Jana, 2009),
featured in abductive thinking (Dorst, 2010; Lockwood, 2010), multidisciplinary aptitude (Meinel & Leifer, 2010),
etc. Designing in fact comprises of various activities of multifaceted nature (Lawson, 2006). Different design
disciplines or programs implement design thinking in a variety of forms (Kelley & Jana, 2009; Kwek, 2011; Meinel
& Leifer, 2010). Variations of the thinking styles between different types of designers have been reported in many
empirical studies (e.g., Akin, 2001; Purcell & Gero, 1996). How these disciplinary variations of design thinking
may affect the collaborations between designers from various backgrounds, however, is under-explored.
Several studies have demonstrated that the education program may have a strong influence on shaping students’
thinking styles and their preferred design strategies. Durling et al. (1996) indicated that, in a personality survey
among various professions, each occupational group (design or non-design) showed a certain type of preference;
designers usually preferred an intuitive way of reasoning. Lawson (1979, 2006) explicitly argued that the
preference of cognitive strategies is a learnt behavior. Senior architecture students preferred solution-focusing
strategies, and no significant disciplinary difference was observed between first-year architecture students and
high school students. This paper is thus interested in evaluating the impacts of different design disciplines on
students’ design thinking patterns, as well as the implications on multidisciplinary design collaborations. Would
the promotion of design thinking pave a common ground for interdisciplinary design collaborations? Or the variety
of existing design-thinking-centered curricula may shape different understandings of design, which cause conflicts
during multidisciplinary teams’ designing process.

2. METHODS
The evaluation of effects of design-thinking curricula was undertaken in an experimental study comparing two
programs of industrial design (ID) and mechanical engineering design (ME) at the National University of
Singapore (NUS), by using a mixture of qualitative approaches, i.e., questionnaire, interview and conceptual
design exercises (Jiang & Yen, 2010). 24 final year undergraduate students (12 from ID and 12 from ME)
participated in this study voluntarily. They were asked to fill a semi-structured questionnaire about their
understanding of design/designing and their preferred design strategies. They were then paired up to form design
teams to undertake two conceptual design exercises. This paper is focuses on the mixed design teams consisting
of one ID and one ME students. It intends to identify the effect of different views of participants on the
multidisciplinary team’s designing process.
After the completion of conceptual design exercises, the participants were asked to provide a short oral
presentation (with visual aids, e.g., sketches) to explain their design concepts. An interview was then carried out
to further understand about their design activities. Questions were posed with regard to their questionnaire
answers and behaviors during the design exercises.
3. TWO DESIGN PROGRAMS IN THE NATIONAL UNIVERSITY OF SINGAPORE (NUS)

NUS is consistently ranked among the best universities in Asia and the world. The programs of ID and ME respectively hold a good reputation in their own fields. Both programs championed design thinking as the essential pillar in their design curricula. The ID division terms design thinking as "out-of-box innovation strategies and investigation methods", and the ME department considers it as "a methodology for innovation". These two programs both value multi-disciplinary aptitude and action-oriented learning approach. They provide conceptual and/or real-life projects on group basis that involve a mix of year 2 to year 4 students from different disciplines. Two program have co-organized a few joint industry-sponsored projects involving ID and ME students (Fuh et al., 2007). There was a joint industry-sponsored project program involving both ID and ME students (Ibid). Students are also strongly encouraged to take modules offered by other faculties, such as humanity, business and management, to broaden their outlook and repertoire of skills (NUS DID, 2010; NUS ME, 2009b).

Both programs seem to consider the “T-shaped thinker” as an ideal expectation for their graduates, who have deep expertise in one domain and enjoy breadth of knowledge, skills and experience in many others (Brown & Katz, 2009; Kelley & Littman, 2005). The vertical element or the specialization in this “T shape” is varied between the two programs. The ID program holds a humanized view of design and declaims that the vision of ID is “to make life better through design” (NUS DID, 2010). ID students are expected to have strong artistic sensibility and able to embody “pleasing and appropriate aesthetics and emotion” in their designs. The ME program possesses a more rational view of designing. It emphasizes the fundamentals of engineering sciences and views design as the application of engineering sciences to produce innovative products (NUS ME, 2009a).

Reflecting on the curricular settings, the first year ME courses are mostly lecture-based, emphasizing on foundations of engineering sciences as well as engineering design principles. In terms of symbolic versus episodic knowledge distinction (Robillard, 1999; Visser, 1995), what ME freshmen learn mainly fits in the former category that is about abstract rules or principles detached from concrete situations. It then slowly progresses to hands-on “design and built” modules that allow students to apply engineering design fundamentals in practice. The ID foundation courses starts straightly with hands-on modules composed with a series of 2D and 3D exercises (Boucharenc, 2008). Episodic knowledge dominates throughout the ID curriculum. Students are immersed in a variety of conceptual and real-life projects. Craft-like ability is also emphasized in ID program.

There is a significant difference identified on the design representation and communication means. The ID program embraces more tangible media, such as freehand sketching and foam modeling, which facilitate deep engagement and allows students to feel and experience designing by multiple dimensions of sensations. They consider the ambiguity of those tangible media can stimulate creativity (Goel, 1995; Goldschmidt, 1991; Purcell & Gero, 1998). Whereas the ME program emphasizes digital media that provide precision in design visualization and modeling. Students are taught computer-aided design and analysis (CAD/CAM) with the aid of state-of-the-art computer software and hardware. These computer-based design tools mainly demand the visual engagement and abstract reasoning, while lacking sensory involvements (e.g., haptic).

In addition, learning environments also differ between these two programs. In the ID program, design studio becomes a hive of activities, including lecturing and self-learning, as well as extra-curricular activities. Tutors spend considerable time in studio that allows many opportunities for unscheduled interaction with students and in-time feedbacks. Though ME program also adopts the project-based teaching, it does not have an ID-studio-like fixed location. Some facilities (e.g., computer cluster, prototyping and tooling room) usually play the role of regular “meeting place” for ME students and tutors (Fuh, et al., 2007).

4. SELF-REPORTED DESIGN THINKING

The self-reported design thinking was extracted in light of questionnaire and introspective reports in the follow-up interviews. The statements were mainly about students’ articulation about their understanding of design, their habitual ways of designing, rather than their memories about specific cognitive processes or textbook contents. Results show that ID and ME respondents seemed to have significant differences with regard to the understandings of design/designing. The reported designing processes were almost identical between the ID and ME students.

4.1. DEFINITION OF DESIGN

ID students usually did not distinguish the meanings of design and ID (n=9), which were both considered as a holistic or human-centric approach composed of aesthetics/art, engineering/technology and business/marketing. ME students tend to see design as an individual stage/phase of a broader engineering design process (n=10).
Figure 1 summarizes the keywords extracted from the self-reported definitions of design. Most ID students (n=11) echoed the vision of the ID program, i.e., to improve experience or everyday lives. Whereas ME students tended to view design as a rational process, such as “creation” (n=7), generating “plan for production” (n=4) and “problem solving” activity (n=4). They may describe design in a neutral or objective way highlighting the materialization aspect of design, such as producing “something new” (n=4). ME students were more likely to rephrases it as “better products” (n=4), emphasizing the value or goals of being achieved. “Innovation”, “aesthetics” and “creativity” were mutually agreed, though both ID and ME students were not emphasized in terms of the relatively low responding rates.

4.2. PRODUCT DESIGN VERSUS ID/ME
When being asked about the subject of this study “Product Design”, all respondents agreed that ID and ME were closely involved in this activity, except 1 ME respondent considered they were “not very linked”. As shown in Figure 2, most students tended to deem “Product Design” as a subset of their professional fields (ID, n=9; ME, n=7). ID students claimed that ID “not only designs physical products ... [it also] creates a new whole experience”, or ID involves system, emotion and/or interactions that product design does not explicitly address. The reasons that ME students thought “Product Design” as a subset of ME were mostly based on the claims that design is a subtopic of ME. The relationship between design and “Product Design”, however, was not well articulated.

4.3. IMPRESSION OF DESIGN
Different iconic images were brought up when students attempted to describe design visually. Figure 3 shows that, ID students mostly reported about domestic appliances (n=10 out of 12) and furniture (n=9) that are used in daily lives, whereas ME respondents were more likely to mention some “hi-tech” products and those had stronger social relation to structure, such as architecture/buildings (n=7) and transportation (n=5). The commercial electronic devices, in particular iPhone and iPods, were the common interests shared by both groups (ID, n=8; ME n=4). Where describing the activities that could represent designing, ID and ME students seemed to have a good consensus. They all mentioned activities like brainstorming, ideation, sketching, modeling and/or prototyping.
4.4. DIFFERENCES BETWEEN ID AND ME DURING DESIGNING

Most respondents agreed that ID and ME thinking seemed to be complementary, though they were both involved in designing products. ID students considered ME was more concerned with technical problems or utility-related aspects of a product (n=9), whereas they were more focused on human values and business aspects of design, such as experience, emotion and aesthetics (n=10). Most ME participants thought they were more concerned with functions or feasibilities of a product (n=9), while ID may deal with styling or aesthetic aspects of a product (n=6). Three ME respondents also reported manufacture cost was an important consideration for engineering design. One ME student seemed to misinterpret the nature of ID and thought it was dealt with the improvement of industrial processes.

4.5. STRATEGIES & DESIGNING PROCESSES

The introspective reports on designing processes and strategies are about students’ metacognitive statements, i.e., their perception about their habitual ways of designing (Hoover & Feldhusen, 1994; Jaušovec, 1994; Yukhina, 2007). These perceptions or beliefs may influence on how participants consciously choose design strategies and monitor/manage their designing processes. Literature has categorized strategies that manage designing processes into three categories, namely top-down, bottom-up and opportunistic (Cross, 2008b; Davies, 1991; Guindon, 1990). All ID respondents were the supporters of opportunistic strategies. Five of them further argued that they would explicitly adjust their strategies or combine top-down and bottom-up strategies according to the given tasks.

ME students seemed to be in favor of systematic strategies. Only two ME respondents championed opportunistic strategies. The rest of respondents either supported top-down decomposition or bottom-up strategies (n=5 vs 5). Although they claimed to adopt different strategies to manage/coordinate designing, the reported designing processes were similar between all respondents, i.e., a sequence of activities transforming design requirements or human needs to a product. Post-test interviews demonstrated that the participants, both ID and ME students, were taught and trained to follow some sort of systematic procedures/methods. Examination of the diagrams of designing process demonstrated that ID students were more aware of the iterations of designing. All ID participants explicitly drew iterations between different stages of designing, whereas only 5 ME students showed the loopback processes in their diagrams. All ME students agreed designing process was not linear and iterations was in fact an important character of designing. This issue was explicitly clarified during their follow-up interviews.

5. MIXED TEAMS’ DESIGN ACTIVITIES

The results of above questionnaire and interviews have demonstrated that ID and ME students may hold very different understanding of design/designing. Reflecting on their behaviors in the two conceptual design exercises, the ID teams demonstrated problem-focused designing styles, whereas the ME teams were strongly solution focused (Jiang, 2012). This section mainly focuses on the design sessions undertaken by the mixed design teams, and explores how the disciplinary differences may influence on the within-team interactions between ID and ME participants.
5.1. ORGANIZATION OF MIXED TEAMS’ DESIGNING PROCESS
The example excerpts shown in Box 1 demonstrate that ID and ME students usually started with a good agreement on the envisioned designing process in the beginning of a design session. There was no significant difference existed in this team between their reported designing processes.

Box 1. Agreements on the designing process excerpted from a Mixed team protocols

| ID: | I just try to understand how do you usually deal with design process? |
| ME: | How to do design process? |
| ID: | Yeah, how do you all ... design stuffs? |
| ME: | Normally we will ... mostly will do problem identifying, brainstorming, possible ... Mhmm possible solutions, then evaluation, select a solution and trouble shot. If there is any problem, we will go back to brainstorming, the possible solution again... |
| ID: | OK, |
| ME: | ... then evaluate it. |
| ID: | Mhmm, some kind of similar with ours |
| ME: | Yeah, I think the main difference is the condition, our requirements. |
| ID: | Yeah... Usually, I guess, your focus will be more on like... you have to do it to all-the-end. |
| ME: | Mhmm, not really. You can just end with coming up with concepts, and set up it on the scenarios. |
| ID: | OK, that’s cool. Then we won’t have any problem with design process. Pretty much the same, haha (laugh) |

The Agreed Model of Designing Process:

- Problem identifying ➔ Brainstorming ➔ Possible solutions ➔ Evaluation ➔ Select a solution ➔ Trouble-shotting

Arguments were often recorded on how a designing process should be executed in the real design session. Box 2 provides an example of disagreements. The ME student often would like to initiate idea generation while the ID student thought they were not ready to move on. The disagreements on steering the designing process required participants to explicitly plan the designing process in order to maintain their cooperation. A systematic procedure that regulated idea generation and evaluation was often the results of their negotiation. It may define each stage of designing with arbitrary milestones, such as “to 3pm, each of us brainstorm 5 ideas” (Mix4 task2). Adhere to the pre-scheduled activities, rather than when both participants considered they were ready to move on, a premature concept may be carried to the next stage of development. It accounted for the great variety in terms of mixed design teams’ design outcomes. For example, the team of Mix3, in the Task 1, produced a well-developed coffee maker concept according to semantic, pragmatic and syntactic aspects of design (Boucharenc, 2008), but their concept for Task 2 elaborated none of the above design dimensions.
5.2. PREFERRED DESIGNING APPROACH

The observations of the control groups suggest that the ID and ME teams respectively followed a schema-drive refinement or case-driven adaption approach (Ball, Ormerod, & Morley, 2004; Oxman & Oxman, 1992). The ID teams usually spent more time on problem exploration and proposed initial ideas that were highly abstract and conceptual. It then followed with a sequence of “refinement” operations to “particularize” the initial schematic state into a detailed description of a specific product (Jiang, 2012). The ME teams tended to use specific precedents to understand the design problem. Different from the ID teams’ “general to specific” process, the ME processes were usually a “specific to specific” process, i.e., adapting a rather detailed precedent or “functional prototype” to accommodate specific requirements of the target situation.

Figure 4 Examples of initial ideas proposed in Mix4 PES

ID and ME student’s preferences on designing approaches were demonstrated in the mixed session’s problem formulation and brainstorming processes. Figure 4 provides some typical initial ideas generated in the brainstorming. ID students tended to use “brainsketching”/visual brainstorming (van der Lugt, 2005), e.g., thumbnail sketches, to visualize human behaviors and possible interactions between users and target product (Figure 4a). The product attributes were usually remained abstract. ME students, to the contrary, preferred to use texts to present their initial ideas. The detailed solution or technology may have already been identified in the initial ideas, such as “GPS”, “console”, “email”, “internet” shown in Figure 4b.

Figure 5 A design cooperated by ID and ME students (Mix3 Task1)

It was difficult to claim the Mixed team used a schema-drive refinement or case-driven adaption approach (Ball, et al., 2004; Oxman & Oxman, 1992). It depended on who led the concept development and detailing design. In the Mixed sessions, once an initial idea was chosen, the person who proposed that idea usually took the responsibility to complete it. The other participant may only provide some comments, instead of active engagement. The interdisciplinary cooperation in solution development was only observed in Mix2 Task 2 and Mix3 Task1. The former session decomposed the solution into several components, which were separately designed by the two participants. In the session of Mix3 Task1, the ID student designed the form and interaction
with users, and the ME student implemented the compositional structure of this product. Figure 5 presents their final drawings. This Figure shows that the envisioned concepts of ID and ME students were actually not well matched.

6. DISCUSSIONS AND CONCLUSION

Literature shows, to handle the increasing complexity of contemporary design problems, designing has shifted from predominantly individual activities towards team-oriented activities (McDonnell & Lloyd, 2009). Interdisciplinary collaborations and “cross-pollination” (Kelley & Littman, 2005) are championed by both design educators and practitioners. The mixed design teams were thus expected to be the most promising group in this study. Their designing process should demonstrate some distinguished, more efficient designing styles and produce better/more creative outcomes. Unfortunately, the evidence gained from this study did not support this argument. ID and ME students may make a stronger contribution in the problem formulation and solution development respectively. But the overall behaviors of the mixed teams seemed to simply be a blend of the characteristics of ID and ME sessions (Jiang, 2012). Moreover, due to the different understandings of design, many conflicts may be raised during the mixed teams’ design sessions. The problems identified are as follows:

- Communication: Though their reported designing processes were similar in vocabulary, the terminologies they used were in fact associated to different meanings.
- Different focuses on problem or solution: The inter-disciplinary differences show that ID teams were generally problem-focused and ME teams were solution-focused. The differences of design focus increased the conflicts or tensions within the multidisciplinary team. ID student tried to “deep dive” into problematic situations and proactively formulate an opportunity to design, whereas ME student attempted to lead the designing process into thoroughly analyzing and optimizing the design solution.

This indicated that the expected advantages of interdisciplinary teams do not come for granted. It requires efficient team building efforts to integrate contributions from various perspectives. Some frameworks (e.g., Macmillan et al., 2001; Reymen et al., 2006) and methods, such as “seeds of cross-pollination” (T. Kelley & Littman, 2005), have been proposed to support interdisciplinary design collaborations. Future empirical studies are required to test how effective and efficient these frameworks and/or methods are to build a highly-performance interdisciplinary design team. Design curricula can be improved through promoting cultural literacy of their neighboring disciplines, as well as other major stakeholders of design practice. The encouragement of interdisciplinary collaboration, e.g., joint ID-ME design projects (Fuh, et al., 2007), should help students appreciate each other strength and understand their complementary aspects of thinking.

REFERENCES


