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Interplay of computer and paper-based sketching in graphic design

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Abstract The purpose of this study is to investigate student designers' attitude and choices towards the use of computers and paper sketches when involved in a graphic design process. 65 computer graphic technology undergraduates participated in this research. A mixed method study with survey and in-depth interviews was applied to answer the research questions. This result shows that sketches and computers as design tools help students generate ideas in the early stage of design. Students' preferences to use sketches or computers differ, since each tool has its own advantages and disadvantages.

Keywords Design process · Design tools · Sketch/drawing · Computer-aided design

Introduction

Design is regarded as a multi-staged (Lewis and Bonollo 2002; Adams 2001), ill-structured problem solving process (Römer et al. 2000). Unlike a structured problem-solving task with a definite solution, design is a process which requires designers to use different skills to identify and analyze problems, synthesize ideas, and then generate and test solutions to create new approaches and objects (Römer et al. 2000; Lewis and Bonollo 2002; Menezes and Lawson 2006). For a novice designer, without sufficient skills and practice, design is a challenging and difficult task (Moor and Deek 2006; Thomasson et al. 2006; Jalil and Noah 2007).

Concept generation is an important phase in design, in which designers brainstorm ideas, develop thoughts and make early decisions (Bilda et al. 2006). This initial thinking process is usually described as full of "ambiguity and fluidity" (Stone and Cassidy 2007, p. 60) as designers have to jump back and forth between abstract thinking and solutions testing (Balasubramanian et al. 1998). This type of thinking process demands extensive

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memory workload in visualizing, analyzing and evaluating ideas. Without sufficient strategies and tools, designers, particularly novice designers, experience difficulties of generating unique/original ideas or a wide range of different solutions (Hokanson 2000; Condoor et al. 1992). As a first step, this study attempts to understand difficulties novice designers meet within the concept generation stage.

In order to overcome difficulties in design, designers use different tools to help them think, among which sketches and computers are the two widely used ones. Previous research indicates that paper sketches enable designers to explore their ideas without giving details in the early stage of design (Lipson and Shpitalni 2000) and sketches could "lighten the load on memory constraints" of designers and "support early design thinking" (Stone and Cassidy 2007, p. 60). Other studies (Stone and Cassidy 2007; Bilda and Demirkan 2003; Jonson 2005) found that computers emerged as an ideation tool among different design domains and designers might use both computer and paper sketches in their design process. It is, however, not clear how designers work with both, paper and computer sketches, and how the different media influence the design process. More research is needed if we want to have a deeper understanding of how computers and paper sketches as design tools complement each other and contribute to different aspects of the design task. In addition, while the literature is rich on professional designers (Suwa et al. 1998; Bilda et al. 2006; Bilda and Gero 2007; Kokotovich and Purcell 2000), a small amount of research addresses how and for what purpose student designers use different tools and how these tools help students design. The research presented in this paper fills these gaps in the literature and ultimately informs design teaching and learning.

Guided by the following questions, this study investigates difficulties student designers meet in the concept generation stage and their attitudes and choices towards the use of computers and paper sketches when involved in a graphic design process. The study further explores how computers and sketches help students to overcome their difficulties in the early stage of design. In addition, since the participants of our study come from two design courses: one is a lower level course and the other one is an advanced level course, we are also interested in comparing the differences between these two groups of students because we believe that examining novices at different levels can help us understand novice designers better.

1. What type of difficulties do student designers meet in design and are there any significant differences or trends of how students' perceptions of difficulty in design differ between students from a lower level course versus those from an advanced level course?
2. Which tools do student designers prefer to use when they are in the concept generation stage of design? For what reasons do student designers choose which tools? How do computer sketching and paper sketches help students conduct design projects?
3. To what extent do paper and computer sketching complement each other for novice designers?
4. What strengths and weaknesses do student designers perceive on themselves, when working on the design task?

Literature review

What is design?

Design is a strategic/systematic method to arrange/organize existing resources and to integrate designer's intuition and imagination into creating something new with practical

function in order to achieve a goal (Rowland 1993) such as to provide solutions to problems, to create a product with aesthetic and practical functions. A number of studies have been done on how designers design. In general, research shows "there is a distinct 'designerly' from of activity that separates it from typical scientific and scholarly activities" (Cross 2006, p. 6).

Lawson (1980) compared strategies designers used to solve problem with those of scientists and found out that while scientists focused on "discovering the rules"; architect designers were more concerned with "achieving the desired results". It was suggested that designers tended to be "solution focused" while scientists were "problem focused". So the central feature of design is its "reliance on generating fairly quickly a satisfactory solution" (Cross 2006, p. 7).

It is also recognized that design problems are ill-defined or ill-structured (Cross 1995; Visser 2006; Reitman 1964), mainly because they have underspecified or ambiguous goals, solutions and methods (Reitman 1964; Simon 1973; Jonassen 2000). These uncertainties make design an open-ended problem solving process and bring challenges to designers.

Process in design/graphic design

Research shows that design is a systematic process, in which designers have to generate ideas, evaluate thoughts and specify details (Dym et al. 2005). The design process consists of distinct stages. For example, in the stage model used by Adams (Adams 2001, 2002; Adams and Atman 1999, 2000), engineering design was broken into eight stages: problem definition, gathering information, generating ideas, modeling, feasibility, evaluation, decision and communicating. This kind of systematic approach might help designers design, especially student designers, as Radcliffe and Lee (1989) found that the degrees to which students followed a structured design process correlated positively with the quality or the effectiveness of design.

However, in practice, designers do not strictly follow this stage model. Fricke's (1993, 1996) research suggested that designers following a "flexible –methodical procedure" (Cross 2001, p. 91) could also generate good solutions. This kind of flexibility could be diverse and unique, depending on individual designer. For example, designers might skip one phase and go directly to the next stage (Günther and Ehrlenspiel 1999). The whole design process could be different for designers because of their preference, education background, etc. (Günther and Ehrlenspiel 1999).

Novice designers are in the initial learning stage of design profession. A systematic guide is usually preferred. The guided process gives a structured procedure for beginners to follow. It can enhance their chances to succeed and boost up their confidence. This study integrates a framework of design process (Hales 1991) and an existing operational model of a design process (Lewis and Bonollo 2002), which is also a staged process, including (1) task clarification, (2) concept generation, (3) elaboration/refinement, (4) detailed design/creation, and (5) communication of results. This model shares many similarities with Adams' (2001), as both of them agree that designers construct the problem first, generate ideas and then work on details.

"Concept Generation" and sketch

Concept generation has been regarded as one of most important stages in design (Pahl and Beitz 1996). It is closely related with creativity design as designers often come up with novel ideas in this stage (Nagai et al. 2009). As previous studies revealed, student designers

had a difficult time in the concept generation stage (Condoor et al. 1992). In this study, we are interested in exploring what kind of difficulties and problems students meet in the concept generation stage.

Concept Generation, also named as ideation and conceptualization (Jonson 2005; Balasubramanian et al. 1998; Tseng et al. 2008), refers to the initial stage of a design thinking process, in which designers work individually or in a group to generate a variety of potential ideas to solve design problems (Lewis and Bonollo 2002). This nature of conceptualization thinking process is "opportunistic and evolutionary" (Balasubramanian et al. 1998, p. 256). The mental activity of a designer is continuously shifting back and forth between abstract thinking and concrete ideas while s/he gains greater insights into the problem (Balasubramanian et al. 1998). During this intricate process thinking process, designers rely on tools or come up with strategies to direct their unleashed mind. Paper sketch is a common tool that designers apply and is recommended in design education (Jonson 2005; Cross 1999; Bilda and Demirkan 2003).

Paper sketches (freehand sketch) as a design tool in the early stage of design

In the early stage of design-concept generation, designers develop and visualize their ideas by using a number of forms of unstructured representations (Purcell and Gero 1998; Menezes and Lawson 2006). One of the widely used external representations is paper sketches, which help designers construct their thoughts (Suwa, Purcell and Gero 1998), recognize emerging features (Purcell and Gero 1998; Cross 1999) and generate more solutions (Stone and Cassidy 2007).

Cardella et al. (2006) studied how engineering student designers used external representations in design activities. They observed that students sketched a lot in the problem scoping stage, which resonates with Römer et al.'s (2000) finding that sketching helps designers to analyze problems. Similar result is also noticed by Cross (2006), who points out that one key feature of paper sketches is that they help designers explore and structure problems. Studies in graphic design further demonstrate that paper sketches play a big role in the early stage of design. For example, Stone and Cassidy's (2007) research shows that graphic designers who used paper-based sketches in the preliminary graphic design decision-making stage produced more solutions than those who used computers.

So why are paper sketches so essential in the design process, especially in the early stage? One reason could be that "sketches enable designers to handle different levels of abstraction simultaneously." (Cross 2006, p. 37). Especially, in the early stage of design, paper sketches provide designers a chance to move between the overall idea and general concept and the detailed aspects of design. This whole process of sketching is regarded as a dialogue or conversation between the designer and what is designed (Goldschmidt 1991; Schon and Wiggins 1992; Purcell and Gero 1998).

Computers as a design tool in the early stage of design

With the development of new technologies, computers as design tools have been widely employed by designers in their practice. In order to investigate the strength and weakness of paper-based and computer-based media's influence on concept generation, Won (2001) conducted an experiment to observe two industrial designers' conceptualization process while using two types of thinking media-conventional (paper-based) and computer media. The result indicates that computers could be helpful to provide immediate externalization

with more details, concrete results; while paper-sketch can help designers generate more solutions in the same amount of time.

LeCuyer (1995) compares two expert architects' approaches to the use of computers in design. In her study, one expert used computer-generated forms at the beginning stage while the other used computer in design development. Computer helped both designers create good design product. Some other benefits of using computer as a design tool is mentioned by Marx (2000), who pointed out design on computer is effective and accurate, especially when design is complex.

However, not all researchers believe computer is a useful tool for designers. For example, Stone and Cassidy (2007) and Won (2001) show that designers who use paper-based sketches produce more solutions than those using computer software. They believe that part of the reason why computers are less helpful than sketches is the technique challenge posed by using computers. Another reason they mentioned could be that the physical act of drawing enables designers to reexamine and reinterpret their thinking, which is lack in computer-aided-design. Fish and Scrivener (1990) discuss why computers are not as powerful in assisting design. They argue that computer systems asks designers to provide too much detailed information at the early stage of design process, which may force designers to make premature decisions and prevent designers from considering alternatives.

As it is shown above, both paper sketches and computers have unique advantages and either can be effective tool in design. In practice, they are often combined to use to solve design problems. However, it still remains unknown that which one student designers prefer to use and how and why these tools can help students design. In this study, we explore how computer and paper sketches support design, especially in the concept generation stage, based on student designers' need and preference.

Student designers

Students who don't have much experience in design are considered novices and in general, experts perform better than novices in a number of aspects: For example, both Batra and Davis (1992), and Crismond's (2001) work, which investigated expertise in design across different domains, found that experts tended to recognize similarities among situations and made connections between their works. Cross (2004) summarized some vital features of expert performance, like the ability to form abstract conceptualizations and recognize principles and theories hidden under the surface. An additional summary of characteristics of expertise was conducted by Bransford et al. (2000, p. 31): "experts notice features and meaningful patterns of information", "experts are able to flexibly retrieve important aspects of their knowledge with little attentional effort" etc.

It takes a long period of time for a novice to become an expert and this expertise development process can be further divided into sequential stages. As Dreyfus and Dreyfus (1986) identify, novices go through progressive stages from novice, advanced beginner, competent, proficient and finally become experts. Thus, it requires a great length of time for a novice to expert transformation. For example, as summarized by Ericsson et al. (1993), the time required for a novice to attain exceptional performance may be over 10 years.

In this study, our participants are student designers. One model that can help us better understand students' expertise is the model of domain learning (MDL) proposed by Alexander (2003). MDL focuses on explanation of learners' expertise development in academic field. In this model, Alexander divides the process of expertise development into

three stages: acclimation, competence and proficiency/expertise. Learners start with limited and fragmented knowledge (acclimation), gradually acquire well-structured solid basic knowledge (competence) and finally become experts with a broad and deep knowledge base (expertise). Urban-Lurain et al. (2006) pointed out that not only does formal education but also professional practice acts in an important role in this novice to expert transformation process.

Existing research on student designers informs us that students use sketches extensively in their design (Cardella et al. 2006) and sketches help them generate more solutions (Stone and Cassidy 2007). However, most of the past studies are based on observations. Not many of them asked students' view about how sketches or computer help them design. This research tends to fill this gap by using a survey and semi-structured interviews to explore students' attitude towards using sketches and computer in the early stage of design. Besides, we explore student designers' advantages and disadvantages in graphic design, which contributes to the literature of novice-expert difference.

Methodological framework

We implemented a two-phase, mixed method study. The literature review helped the research have further understanding of the current findings of relevant studies. Then we used a survey generated from class observations to identify participants' difficulties during a design process/project. Then the semi-structured, face-to-face interview was conducted to further understand participants' preference and reasons for selecting a tool to facilitate their idea generation.

Research methods and instruments

The observation was conducted as a qualitative and explorative process in a natural classroom context. The purpose was to gather data to record potential difficulties that student designers encountered in working on design projects, when using computer-aided or paper-based sketches as tools for idea generation.

The survey we designed consisted of 71 items measuring various problems students might meet in five different stages of design: Task Clarification, Concept Generation, Evaluation and Refinement; Detailed design of preferred concept and Communication of results. Another 17 items were general questions related to skills and preference, etc. All items were measured on a 7-point Likert scales, ranging from "very strongly disagree" to "very strongly agree".

The semi-structured, face-to-face interviews followed after the survey and served three purposes in this research: (1) gather in-depth description about student designers' preference of tools selection; (2) understand reasons that lead to their tool selection preference; (3) understand how student designers perceive the role sketches and computers play in their design process. The interviews were voice recorded and transcribed into written texts. Comments were marked when reading through all the interview data to acquire general understanding. Later, the coding process helped to group each individual's statement into broader themes or categories, which directed our findings to explain the possible reasons of novice designers' tool selection preference. The direct quotes from the interview were used as evidences in the qualitative data analysis and discussion of this paper. The quotes are printed verbatim without grammatical error correction.

Participants

The study was conducted in a computer graphic program of a large Midwestern university in the United States. The two undergraduate courses-CG01 and CG02-observed in this study were offered in the computer graphic technology (CGT) program. CG01, a required foundation course for CGT freshmen, is designed for students to acquire and implement basic design knowledge, such as typology, aesthetic elements and principles for visual communication. CG02 is a selective course for students to take in their 6th semester or above. The purpose of CG02 is to support students who are interested in interactive multimedia and design careers, to advance their knowledge and skills in prepress production and design. In CG01, students design flyer, calendar and postcard. In CG02, students design magazine spread, identities (logo, business card and letters), books (cover, intro, and title page). See in Table 1 for details on the students' demographic information,.

Within these two courses, students needed to finish three to four big projects every two or three weeks. For developing each project, the instructor asked students to brainstorm their ideas by hand sketching on papers and turning them into drafts before actually working on the computer to create the final products in the electronic forms. The instructor

Table 1 Demography information of participants and their design tasks

Courses	CG01	CG02
Participants in survey	46 (7 females; 39 males)	19 (8 females; 11males)
Participants in interview	21 (4 females; 17 males) Semi-structured & face-to-face interview	16 (6 females; 10 males) Semi-structured & face-to-face interview,
Sketching skill	One sketch course is required to take before or while taking CG01	One sketch course is required to take in the first semester in CGT program
Participants recruited and data collected time & year	Spring, 2009	Fall, 2008
Design projects	Practice basic design elements, principles, composition and typology to communicate visually by solving exercise problems and designing projects like flyer, calendar, and postcard	Design single and multiple- page documents for business, advertising such as identities, flyers, brochures, forms, catalogs, newsletters and booklets
Teaching procedures	Lecture Present topics (such as color theory); introduce exercise and projects (explain requirements, share examples) Lab Practice exercises: imitate the special effects of a sample image, the purpose is to getting familiar about how to use In-Design Projects: hand-sketch draft first; submit drafts and discuss with instructors/ TAs to select one to actually realize on computers; work on their projects and seek helps/comments from instructors, TAs or classmates	Lecture Present topics (such as prepress process); introduce exercise and projects (explain requirements, share examples) Lab Practice exercises: imitate the special effects of a sample image, the purpose is to getting familiar about how to use In-Design) Projects: hand-sketch draft first; submit drafts and discuss with instructors/ TAs to select one to actually realize on computers; work on their projects and seek helps/comments from instructors, TAs or classmates
Software	Photoshop, Illustrator, InDesign	Photoshop, Illustrator, InDesign

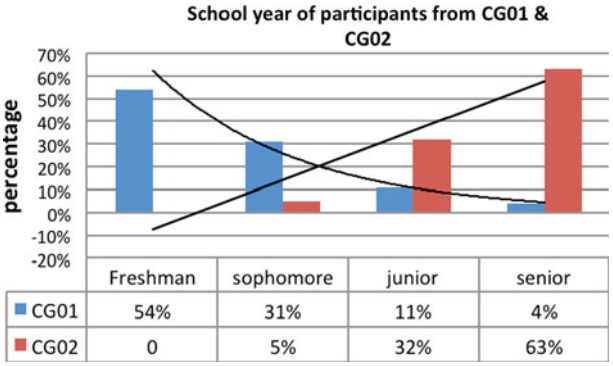

Fig. 1 School year of participants from CG01 & CG02 class

would communicate with students of their hand-sketch drafts and selected one or combined some of the components to generate one final draft to work on for the realization stage.

All the CGT majors are asked to take one required sketching course in their first semester to ensure their sufficient foundation in sketching skills to enter the professional level in CGT program.

The majority of the students from CG01 are freshmen or first year students (Fig. 1) and over half of the students (27 out of 46) have previous graphic design experience before. Approximately half of the students mentioned that they only had less than one year of graphic design experience (Fig. 2). Besides, only three students have taken an intern, part-time or full-time job related to graphic design. Compared with students from CG01, we find the 63 % of the students from CG02 are seniors (Fig. 1) and all of the students mentioned they had graphic design experience before. Students' years of experiences vary a lot, from less than 1 year to more than 4 years (Fig. 2). More than half of the students (11 out of 19) have taken an intern, part-time or full-time job related to graphic design. Thus we can say participants from CG02 in terms of school year and years of design experience are generally more senior than participants from CG01.

Quantitative results and discussion

1. What type of difficulties do student designers meet in design and are there any significant differences or trends of how students' perceptions of difficulty in design differ between students from a lower level course versus those from an advanced level course?

In order to compare whether there are any differences between students from CG01 and CG02 in terms of what difficulties they encounter in the design process, we first calculated the difficulty level of each design stage indicated by students from CG01 and CG02. The result is shown in Table 2. A further *T* test showed that there is no significant difference between the difficulty levels of each design stage for students from CG01 and CG02, indicating that while students from CG02 have more experience, they are similar to CG01 students. We think this similarity between students' responses may be the difficulty/feeling of uneasiness of generating concepts is a shared challenge among designers no matter how long or the expertise level they are. Maybe for a beginner or more advanced novice

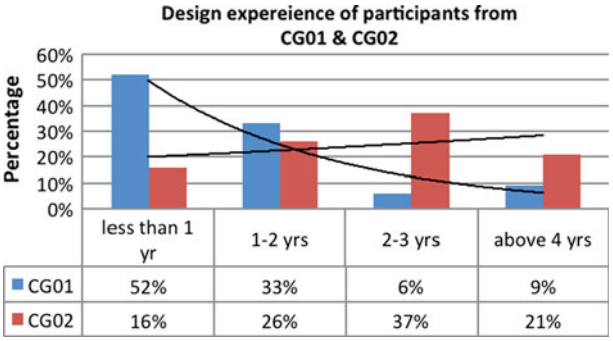

Fig. 2 Years of graphic design experience of participants from CG01 & CG02

Table 2 Difficulty level of five design stages indicated by students from course CG01 and CG02

	CG01 (Level of difficulty: 5 = highest)	CG02
Stage 1: Task clarification	3.34	3.15
Stage 2: Concept generation	4.18	3.99
Stage 3: Evaluation and refinement	3.36	3.53
Stage 4: Detailed design of preferred concept	3.21	2.75
Stage 5: Communication of results	3.39	3.5

designers, they both experienced the conceptualization as their biggest challenge in conducting every new design. However, according to their more experience/years in conducting designs, their time/efforts/strategies put on brainstorming might vary from person to person or from projects to projects.

Another potential explanation is that students from CG01 and 02 are all novice designers and their knowledge or understanding may be in the similar level. Literature indicates novices go through progressive stages to become experts (Dreyfus and Dreyfus 1986; Alexander 2003) and it takes a long time for a novice to grow into an expert (Ericsson et al. 1993) and both formal education and professional practice are needed in this process (Urban-Lurain et al. 2006). Therefore, despite the fact that students from CG02 have more design experiences than students from CG01, the growth or the development of expertise might still be hard to detect.

Since we found no statistically significant difference between the difficulty levels of each design stage indicated by students from CG01 and CG02, for the rest part of quantitative data analysis, we treated students from CG01 and CG02 as a whole group. We first analyzed what difficulties those students meet in the design process. The descriptive statistics in Fig. 3 indicate that students find problems in stage 2 (Concept generation) are most difficult to cope with. The overall difficulty level of stage 2 is 4.12, based on the 7-point scale. Compared with the difficulty level of other four stages, all of which are under 3.5, this number is greater, although this difference is not significant. Besides, among the top five difficult problems students meet in the whole design process, three of them belong to stage 2. The top two difficult problems are "generating a wide range of concepts" with difficulty level 5.03 and "coming up with creative or original ideas" with difficulty level 4.42, both of which are from stage 2 (Fig. 4). Therefore, it is further demonstrated that

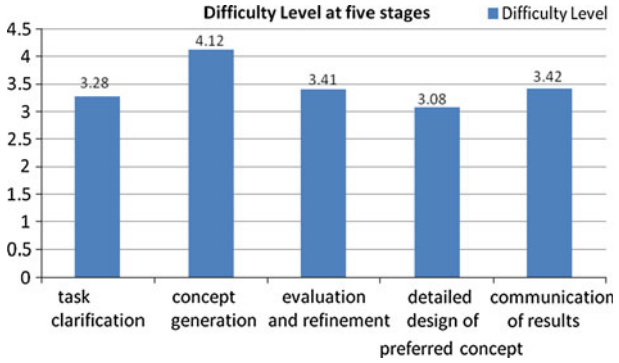

Fig. 3 Difficulty level of five stages. (Stage 1: task clarification, stage 2: concept generation, stage 3: evaluation and refinement, stage 4: detailed design of preferred concept, stage 5: communication of results)

students have a difficult time in generating ideas and concepts. These findings are supported by previous studies on student designers. For example, Condoor et al. (1992) note that students are lack of ability to generate alternatives and they exhibit design fixation. Hokanson's (2000) study of student designers also shows that "Getting the ideas and refining them is the hardest part" (p. 82).

2. What role does sketching play in design?

Previous research suggests sketching is an effective tool for designers, particularly in the early stage (Purcell and Gero 1998; Cross 1999). Our analysis (Table 3) does show that students who sketch and take notes by hand to analyze problems tend to rate a lower difficulty level of all five design stages as we found that there is a negative correlation between the item "sketch and take notes by hands to analyze problems" with the difficulty level of each design stage. This correlation is especially significant in the concept generation stage.

Analysis of strategies students find useful in the concept generation stage (stage 2) shows that students find paper sketches somewhat useful to help them generate ideas. The average score of "Jotting down ideas on papers" (2g) and "Drawing varied versions of sketches for the final selection" (2m) is 4.72 and 4.95, respectively (Table 4).

In sum, our quantitative data analysis indicates that paper sketches are helpful for students in the concept generation stage. Since computers are also provided in this study as a design tool, in the interview session, we further explore students' preference on design tools and how computers and paper sketches help them design.

Qualitative results and discussion

1. Which tools do student designers prefer to use when they are in the concept generation stage of design?

According to the quantitative data analysis result, participants encountered difficulties in conceptualization stage and they indicated sketches were somewhat helpful for them to generate ideas. This result resonates with previous studies, which suggest sketch is one of the popular tools/solutions that designers use to solve their problems in the brainstorming

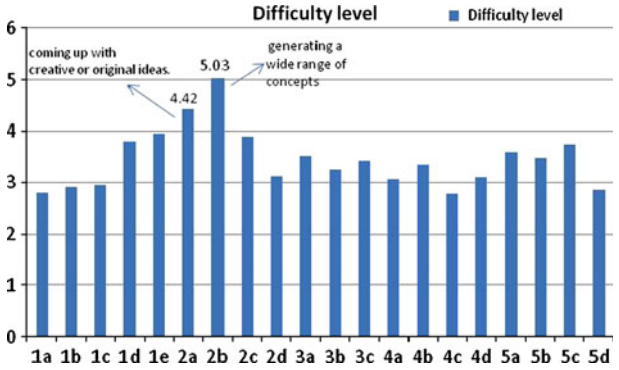

Fig. 4 Difficulty level of each specific problem. (1a–e are problems which might happen in stage 1. 2a–d belongs to stage 2. 3a–c for stage 3. 4a–d for stage 4. 5a–d for stage 5)

Table 3 Correlation between sketch and each design stage

	Stage 1: Task clarification	Stage 2: Concept generation	Stage 3: Evaluation and refinement	Stage 4: Detailed design of preferred concept	Stage 5: Communication of results
I sketch and take notes by hands to analyze problems					
Pearson correlation	−0.279*	−0.375**	−0.105	−0.212	−0.075
Sig. (2-tailed)	0.024	0.002	0.404	0.090	0.554
N	65	65	65	65	65

* Correlation is significant at the 0.05 level (2-tailed)

stage. Based on those findings, we used qualitative interviews to further understand why sketches help and why participants prefer paper sketches or computer-aided sketches.

The qualitative data were first analyzed separately for lower level course (CG01) and advanced level course (CG02) in order to see how design experience may influence students' preference of design tools. There were 21 students volunteering for the interview from CG01 and 16 students from CGT 02. Table 5 and Fig. 5 represent students' preference of tools in the idea generation stage. The result didn't show much difference between these two groups. Both groups show the tendency that about 40–50 % percent of interviewees prefer computer-aided sketch (CG01: 48 %; CG02: 44 %), 33–37 % like hand sketching tools (CG01: 33 %; CG02: 37 %), and the average of 16 % (19 % CG01; 13 % CG02) used both tools depending on their mood and needs (such as efficiency, or accessibility of tool). One interviewee from CG02 would rather take notes to record ideas due to her self-reported lack of good sketching skills.

2. For what reasons do student designers choose which tools? How do computer sketching and paper sketches help students design?

In their design course, students were asked to sketch out their ideas first and then to work on computers to accomplish the final design. Our interviews showed that while a number of students (7 out of 21 from CG01 and 6 out of 16 from CG02) liked to use paper sketches, many others (10 from CG01 and 7 from CG02) preferred working on computers.

Table 4 Solutions related to hand sketch or computer-aided tool to generate design ideas

Stage 1: Task clarification (understand a task)		Stage 2: Concept generation (generate ideas on sketches)		Stage 3: Evaluation and refinement (decide which one or two sketches as drafts to finalize)		Stage 4: Detailed design of preferred concept (collect objects and use software to create the project)		Stage 5: Communication of results (present my design and receive feedback from the others)	
Strategy	Useful	Strategy	Useful	Strategy	Useful	Strategy	Useful	Strategy	Useful
1h	5.05	2g	4.72	3f	5.05	4g	4.1	5g	5.42
1i	5.69	2 h	3.74	3h	5.28	4h	4.91	5h	3.55
1j	3.58	2i	4.75	3i	5.19	4i	4.91	5i	4.58
1k	4.86	2j	4.38	3j	4.06	4j	3.78	5j	3.8
1l	4.98	2k	5			4k	3.85	5k	3.97
1 m	4.65	2l	4.92			4l	5.45		
1n	4.72	2m	4.95			4m	3.77		
1h: Understanding instructors' oral explanation 1i: Understanding instructors' explanation with text and examples 1j: Asking instructors in the big class 1k: Asking instructors in the face-to-face discussion 1l: Listening to questions classmates asked 1m: Taking notes to clarify the task 1n: Discussion with classmates		2g: Jotting down ideas on papers 2 h: One by one discussion with the instructor 2i: Discussion or observing with classmates 2j: Discussing with people outside the class 2k: Getting inspiration outside the classroom 2l: Seeking visual examples via the Internet 2m: Drawing varied versions of sketches for the final selection		3f: Working on my preference 3 h: Taking instructors' suggestions 3i: Consulting others' suggestions (classmates, people outside the class) 3j: Testing several sketches on the software		4g: Checking software books/ user guides 4h: Seeking help from instructor 4j: Seeking help from classmates 4k: Taking notes and analyzing problems I faced 4l: Continuing to work with software (playing around & having fun) 4m: Using self talk to identify problems or release emotions		5g: Spending more time on the project outside of the class to meet the deadline 5h: Practicing the presentation 5i: Observing classmates performance 5j: Jotting down notes to present ideas 5k: Sharing personal difficulties encountered during the realization process with instructors and classmates	

Note: Table 4 is a list of all the strategies we offered in the survey for participants to identify that what strategies they have applied to deal with certain high frequent problems that they have encountered in each stage. For example, when encountered the problem to understand the objectives of the task in "task clarification" stage, the potential strategies would be like asking instructors questions in the big lecture, or looking at the explanations delivered by written text and visual examples. All these strategies we listed were generated from classrooms observations and literature review. We grouped certain strategies in a stage due to their high frequent application in that stage. Therefore, in the concept generation stage, even if we recognized that understanding the task requirement is relevant to facilitate concept generation, but for being more specific to deal with the problems of concept generation such as difficulties of coming up with creative/original ideas, or problems generating a wide range of concepts, we don't include strategies such as 1i (understand instructors' explanation with text and examples) in the options for participants to select. However, for not to restricting their thinking of solutions, there is an option open for sharing other ways that they found useful in concept generation stage. So that is why even if 1i, 3h, 4l, and 5g got scores more than 5.2, they are not directly included in our discussion of solutions relevant to sketches by hands and computer-aided tools. But they are reasonably relevant solutions to support the process of concept generation either in identifying problem scope or in making decision of choosing the final drafts

Table 5 Interviewee's sketch tools preference

Course/sketch tool	Work on computer	Hand sketch	Depending	Others
CG01	10 (48 %)	7 (33 %)	4 (19 %)	0 (0 %)
CG02	7 (44 %)	6 (37 %)	2 (13 %)	1 (take notes, 6 %)
CG01 and CG02	17 (46 %)	13 (35 %)	6 (16 %)	1 (take notes 3 %)

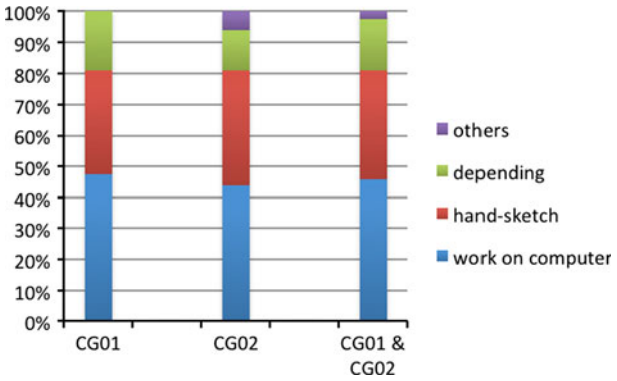

Fig. 5 Preference of sketch tool from course CG01, CG02, and the combination (CG01 and CG02)

The reason why students prefer different tools are showed in details in Fig. 6. In the following paragraphs we analyze and summarize some of the important reasons we find in the interview data.

Students who liked to sketch explained why they thought paper sketches helped them design. The primary reason would be paper sketches helped students generate and visualize ideas and these general, basic and rough ideas became the starting point of their design. For example, one student commented: "I like to do very basic sketches to kind of get a general idea…. I don't think necessarily like really detailed sketches are that important. Just like really basic concept sketches are really important um and then once you choose an idea then you go and do further detailed sketches." Students also pointed out that it was easier to get started with sketching out ideas. They thought "it's just a quick way to put your ideas down" "it is so easy to just whatever draw it out".

Furthermore, several students mentioned that sketches would help them remember their initial ideas so they could always come back, which is also supported by previous study (Purcell and Gero 1998; Cross 1999; Ullman et al. 1998) that sketching provided external memory to aid the designers.

Besides, sketching as movements of hands also had positive impact on students, like one student said he "likes physically drawing it". This finding resonates with previous research which indicated that the physical act of drawing enabled designers to reexamine and reinterpret their thinking (Stone and Cassidy 2007).

In contrast, students who preferred working on computers complained the disadvantages of paper sketches. Some found sketching was time-consuming and since their design on computers was always different from their sketches, they did not want to spend time sketching, like students said "what you see on the computer is a lot different than what you draw up" "it's time consuming because I never like my original ideas anyways so I waste

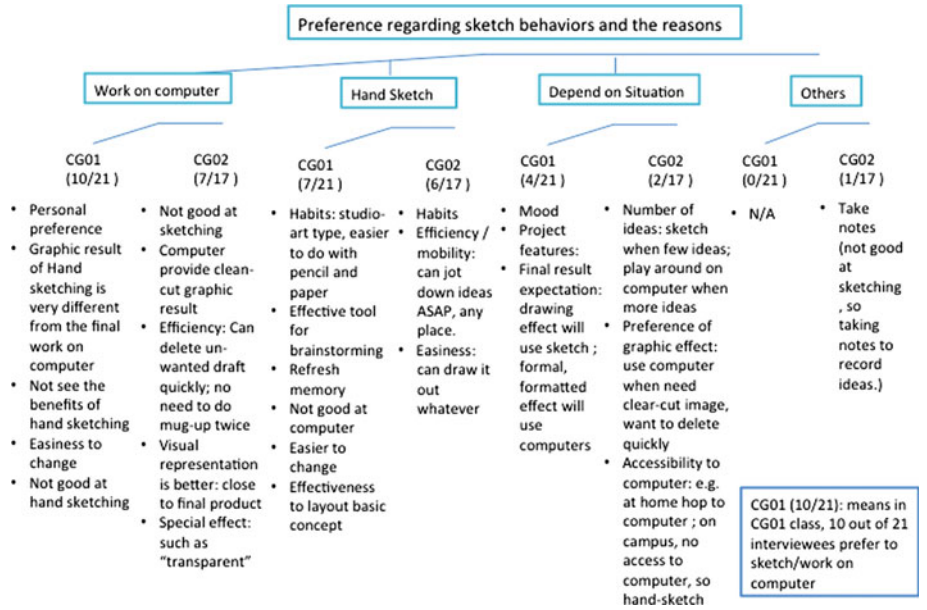

Fig. 6 Interviewee's preference regarding sketch behaviors and their reasons

my time sketch because I never use my sketches". There were also students who felt they did not have the sketching skills, which prevented them from sketching, like one student said: "I know my hand sketches—they are not gonna be all that great". Another student even said that he could not visualize his ideas by using sketches: "when I'm sketching things out I don't know what it's going to look like and as a final product".

Many students agreed that computers worked as an effective tool for them. Their design looked more formatted and clean in computers, like one student said: "a lot of things on the computer are very crisp and clean straight lines." More importantly, students found it was easier to change their design on computers and the design tools provided by software could help bring different effects and try new ideas. For example, there were comments like "The different tools in computer software help a lot to add things and try new." "With the computer you can look up a bunch of different effects." "I don't necessarily have the right sketching skills to make it appear on the paper like if you want something to be transparent or change the opacity or something it's hard to draw that. So it's easier to go to the computer and do it that way". This finding ties back to Marx's (2000) idea that computers are more effective to visualize ideas when design is complex and also echoed Won's (2001) observation that the sketch process done by computer provides designers more immediate representation with better details and concrete visual effects which are more close to the end-product. In addition, students found it was more convenient to share the design with other people when working on computers, like one participant said: "I can instantly email them (clients) a jpeg and be like 'bam.'"

Working on computers also has its own disadvantages, as one student said: "(working on computers made me) be too much of a perfectionist on the early stages like focus too much on something small instead of just quickly try to get the overall look." Previous

research did indicate that one of the reasons why computer was not that powerful was that it forced designers to provide detailed information too early in the design process, which might lead to premature decisions and prevent designers from considering alternatives (Fish and Scrivener 1990).

3. To what extent do paper sketches and computers complement each other for novice designers?

Most difficulties students meet in the conceptualization phase are related with generating ideas. The qualitative data from this study and the previous research (Purcell and Gero 1998; LeCuyer 1995; Won 2001; Jonson 2005) indicate that sketches and computers are important tools to help students generate ideas. To some extent, we can say that designers generate ideas in the process of sketching or working on computers, like one student said: "I don't like brain storm ideas I just start drawing and I go from like I start somewhere and just see where I can go and make it look good". The sketch-first method may still be a good choice for many students as sketches can help them generate a basic idea and the later work on computers gives them chances to work on details. However, as Jonson's (2005) study pointed out, the traditional view of paper sketching as the primary conceptual tool is challenged in this digital age. Nearly half of the participants prefer working on computers. This indicates that computers as a design tool are becoming powerful and helpful for students.

4. What strengths and weaknesses do student designers perceive on themselves, when working on the design task?

Compared with expert designers, novices are still lack of knowledge and experience in design. They are incompetent in some areas and have room for improvement.

One distinct disadvantage for novice designers that we noticed in this study is their lack of computer/sketching skills. Even though most of the students were asked to take a required sketching course in their first semester in the CGT program, not all of them felt satisfied or confident with their current sketch skills. Therefore, this could be a potential obstacle, which decreases some students' confidence and preference on using computer-aided or hand-sketching tools to record or develop ideas. Another notable drawback is the lack of experience and capability to visualize their design. Many students have to rely on computer software to help them visualize the real subject and different effects and a group of students said they found their design in computers was very different from sketches, which, on the other hand, reflects their disability to generate imagery either by mind or by hand. Compared with novice designers, experts have been exposed to a great number of examples and are more capable to mentally form abstract conceptualizations (Cross 2004).

Despite these disadvantages, novice designers are striving for progress and willing to try different ways to improve their design. One student who usually directly worked on computers said he began to notice that sketches could help him get good ideas. Another one also admitted he found the value of sketches after finishing the course. It indicates that through experiencing drawing or hand sketching, students can find the value of using paper sketches to enhance their idea generation. Schenk (2005) also found out that practitioners in the graphic design industry, when working with logo and typeface design, still produced a wide range of sketches in the early stage of design. Therefore, we can assume that on either novice or experts level, hand sketching has its unique value to externalize and develop initial ideas even if digital design tools have been widely applied to facilitate design activities.

Conclusion

This research shows that sketching and computer as design tools help students generate ideas in the early stage of design. Each tool has its own advantages. In summary, sketching is an efficient tool to bring out and visualize initial ideas. Paper sketches help students get a general and basic understanding of their design. However, paper sketching may be time consuming and cannot provide immediate results that have the clean cut and formatting which is close to an end product. Sketching on computers enables students to work on more details. Students could see real objects and use software to try different effects. However, as students are forced to provide more details when working on computers, it does not allow much room for imagination and creativity as paper sketching does.

For instructors who teach design, it may be worth to consider helping students recognize both the benefits and disadvantages of using sketches and computers before starting the design. When introducing externalization tools for idea generation, a graphic design instructor may utilize proven principles such as demonstration (show how), application (practice/hands-on), activation (relate to prior knowledge) and integration (integrate new knowledge to real-life problem solving) (Merrill 2009). If novice learners such as first-year students in graphic design lack sufficient skills in using both paper sketches and computers, instructors need to provide more practice activities for students to be proficient in using those tools. When students question the value of these design tools, the instructor can demonstrate and provide a discussion opportunity for students with different experiences to communicate and guide them to analyze the limitation and advantages of each tool.

Before deciding which instructional strategies to use to improve students' application of sketching tools to facilitate their idea generation in design, a very essential step is to recognize and find out students' difficulties and problems in learning. This study offers graphic design educators empirical evidence to understand students' difficulties in design and preference of sketching tools. Instead of forcing students to use one tool or both, a reasonable way would be to strategically guide students to experience each tool and decide which tool is more suitable for them.

References

Adams, R. S. (2001). *Cognitive processes in iterative design behavior*. Doctoral dissertation, University of Washington, Seattle, WA.

Adams, R. S. (2002). *Understanding design iteration: Representations from an empirical study*. Paper presented at the common ground, design research society international conference, London, UK.

Adams, R. S., & Atman, C. J. (1999). *Cognitive processes in iterative design behavior*. Paper presented at the frontiers in education conference 29th annual, San Juan, Puerto Rico.

Adams, R. S., & Atman, C. J. (2000). *Characterizing engineering student design process: An illustration of iteration*. Paper presented at the American society for engineering education annual conference, St. Louis, MO, United States.

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proficiency. *Educational Researcher, 32*(8), 10–14.

Balasubramanian, V., Turoff, M., & Ullman, D. (1998). *A systematic approach to support the idea generation phase of the user interface design process*. Paper presented at the system sciences, Proceedings of the Thirty-First Hawaii international conference, Kohala Coast, HI, USA.

Batra, D., & Davis, J. G. (1992). Conceptual data modeling in database design: Similarities and differences between expert and novice designers. *International Journal of Man-Machine Studies, 37*(1), 83–101.

Bilda, Z., & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies, 24*(1), 27–50.

Bilda, Z., & Gero, J. S. (2007). The impact of working memory limitations on the design process during conceptualization. *Design Studies, 28*(4), 343–367.
Bilda, Z., Gero, J. S., & Purcell, T. (2006). To sketch or not to sketch? That is the question. *Design Studies, 27*(5), 587–613.
Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. Washington, DC: National Academy Press.
Cardella, M. E., Atman, C. J., & Adams, R. S. (2006). Mapping between design activities and external representations for engineering student designers. *Design Studies, 27*(1), 5–24.
Condoor, S. S., Shankar, S. R., Brock, H. R., Burger, C. P., & Jansson, D. G. (1992). A cognitive framework for the design process. *Design Theory and Methodology American Society of Mechanical Engineers, 42*, 277–281.
Crismond, D. (2001). Learning and using science ideas when doing investigate-and –redesign tasks: A study of naïve, novice, and expert designers doing constrained and scaffold design work. *Journal of Research in Science Teaching, 38*(7), 791–820.
Cross, N. (1995). Discovering design ability. In R. Buchanan & V. Margolis (Eds.), *Discovering design: Explorations in design studies* (pp. 105–120). Chicago: University of Chicago Press.
Cross, N. (1999). Natural intelligence in design. *Design Studies, 20*(1), 25–39.
Cross, N. (2001). Design cognition: Results from protocol and other empirical studies of design activity. In C. M. Eastman, W. M. McCracken, & W. C. Newstetter (Eds.), *Design knowing and learning: Cognition in design education*. New York: Elsevier Press.
Cross, N. (2004). Expertise in design: An overview. *Design Studies, 25*(5), 427–441.
Cross, N. (2006). *Designerly ways of knowing*. London: Springer.
Dreyfus, H., & Dreyfus, S. (1986). *Mind over machine: The power of human intuition and expertise in the era of the computer*. New York: Free Press.
Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking teaching and learning. *Journal of Engineering Education, 94*(1), 103–120.
Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363–406.
Fish, J., & Scrivener, S. (1990). Amplifying the mind's eye: Sketching and visual cognition. *Leonardo, 23*(1), 117–126.
Fricke, G. (1993). Empirical investigations of successful approaches when dealing with differently précised design problems. In *International conference on engineering design ICED*93, Heurista, Zürich.
Fricke, G. (1996). Successful individual approaches in engineering design. *Research in Engineering Design, 8*(3), 151–165.
Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal, 4*(2), 122–143.
Günther, J., & Ehrlenspiel, K. (1999). Comparing designers from practice and designers with systematic design education. *Design Studies, 20*(5), 439–451.
Hales, C. (1991). *Analysis of the engineering design process in an industrial context*. Eastleigh, UK: Grants Hill Publications.
Hokanson, B. (2000). *Accelerated thought: Electronic cognition. Digital image creation and analysis as a means to examine learning and cognition*. Doctoral dissertation, University of Minnesota.
Jalil, M. A., & Noah, S. A. M. (2007). The difficulties of using design patterns among novices: An exploratory study. In *ICCSA*'07 *Proceedings of the 2007 international conference computational science and its applications*, *IEEE*, (pp. 97–103).
Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85.
Jonson, B. (2005). Design ideation: The conceptual sketch in the digital age. *Design Studies, 26*(6), 613–624.
Kokotovich, V., & Purcell, T. (2000). Mental synthesis and creativity in design: An experimental examination. *Design Studies, 21*(5), 437–449.
Lawson, B. (1980). *How designers think*. London: Architectural Press.
LeCuyer, A. (1995). Design on the computer. *Architectural Review, 197*, 76–79.
Lewis, W. P., & Bonollo, E. (2002). An analysis of professional skills in design: Implication for education and research. *Design Studies, 23*(4), 385–406.
Lipson, H., & Shpitalni, M. (2000). Conceptual design and analysis by sketching. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 14*(5), 391–401.
Marx, J. (2000). A proposal for alternative methods for teaching digital design. *Automation in Construction, 9*(1), 19–35.
Menezes, A., & Lawson, B. (2006). How designers perceive sketches. *Design Studies, 27*(5), 571–585.

Merrill, M. D. (2009). First principles of instruction. In C. M. Reigeluth & A. A. Carr-Chellman (Eds.), *Instructional-design theories and models volume III: Building a common knowledge base* (Vol. III, pp. 41–56). New York: Routledge.

Moor, B. D., & Deek, F. P. (2006). On the design and development of a UML-based visual environment for novice programmers. *Journal of Information Technology Education, 5*, 53–76.

Nagai, Y., Taura, T., & Mukai, F. (2009). Concept blending and dissimilarity: Factors for creative concept generation process. *Design Studies, 30*(6), 648–675.

Pahl, G., & Beitz, W. (1996). *Engineering design: A systematic approach*. London: Springer.

Purcell, A. T., & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies, 19*(4), 389–430.

Radcliffe, D., & Lee, T. Y. (1989). Design methods used by undergraduate engineering students. *Design Studies, 10*(4), 199–207.

Reitman, W. R. (1964). Heuristic decision procedures, open constraints, and the structure of ill-defined problems. In M. W. Shelly & G. L. Bryan (Eds.), *Human judgments and optimality*. New York: Wiley.

Römer, A., Leinart, S., & Sachse, P. (2000). External support of problem analysis in design problem solving. *Research in Engineering Design, 12*(3), 144–151.

Rowland, G. (1993). Designing and instructional design. *Educational Technology Research and Development, 41*(1), 79–91.

Schenk, P. (2005). Before and after the computer: The role of drawing in graphic design, visual: design: scholarship. *Research Journal of the Australian Graphic Design Association, 1*(2), 11–20.

Schon, D. A., & Wiggins, G. (1992). Kinds of seeing and their functions in designing. *Design Studies, 13*(2), 135–156.

Simon, H. A. (1973). The structure of ill-structured problems. *Artificial Intelligence, 4*, 181–201.

Stone, C., & Cassidy, T. (2007). Comparing synthesis strategies of novice graphic designers using digital and traditional design tools. *Design Studies, 28*(1), 59–72.

Suwa, M., Purcell, T., & Gero, J. S. (1998). Macroscopic analysis of design processes based on a scheme for coding designer's cognitive actions. *Design Studies, 19*(4), 455–483.

Thomasson, B., Ratcliffe, M., & Thomas, L. (2006). *Identifying novice difficulties in object oriented design*. Paper presented at the 11th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education, New York, NY, USA.

Tseng, I., Moss, J., Cagan, J., & Kotovsky, K. (2008). The role of timing and analogical similarity in the stimulation of idea generation in design. *Design Studies, 29*(3), 203–221.

Ullman, D. G., Dietterich, T. G., & Stauffer, L. A. (1998). A model of the mechanical design process based on empirical data. *AI EDAM, 2*(1), 33–52.

Urban-Lurain, M., Anderson, C. W., Parker, J., & Richmond, G. (2006). *Fluency with information technology in teacher education: Moving from novice towards expertise*. Paper presented at the Society for Information Technology & Teacher Education, Orlando, FL.

Visser, W. (2006). *The cognitive artifacts of designing*. New Jersey: Lawrence Erlbaum.

Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages in design. *Automation in Construction, 10*(3), 319–325.

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