

AC 2010-1163: INTERPLAY OF COMPUTER- AND PAPER-BASED SKETCHING IN DESIGN

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Introduction:

Concept generation is an important phase in design, when designers start generating ideas and develop thoughts. One of the tools that designers use to help them think during this early stage of design is paper-based-sketches. Previous research indicates that paper sketches can help designers better communicate their ideas and progress their design³⁰. However, new technologies, such as computer software that relates to visual representation and design, are impacting the traditional paper-based design. As few studies focus on the comparison between computer-aided-design and traditional-paper-based design^{42, 5, 26}, it is still not clear how designers work both with paper sketches and computers 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 research on professional designers, little research addresses how and for what purpose student designers use different tools and how these tools help students design. This research can inform the teaching of design.

Guided by the following questions, this research presents work that examines student designers' attitude and choices towards the use of computers and paper sketches when involving in a graphic design process and explores how computers and sketches help students in the early stage of design.

- 1) What kind of difficulties students meet in the concept generation stage?
- 2) Which tool do student designers prefer to use when they are in the concept generation stage of design? How do computers and paper sketches help students design?
- 3) To what extent do paper sketches and computers 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

1) Design process

What is design?

A number of studies have been done on how designers design. In general, research shows that design activity is different from typical scientific and scholarly activities. A distinct “designerly” form separates design from other activities¹⁰. Lawson²⁸

compares the problem-solving strategies of designers with those of scientists and finds out that while scientists focus on “discovering the rules”; architect designers are more concerned with “achieving the desired results”. It is suggested that designers tend to be solution focused while scientists are problem focused. So the central feature of design activity is its “reliance on generating fairly quickly a satisfactory solution”¹⁰ (Chap1, p7).

It is also recognized that design problems are ill defined or ill-structured^{12, 45, 38} because design problems have underspecified or ambiguous goals, solutions and methods^{38, 41}. These uncertainties, not only bring constraints to design but also make design an open problem. Jonassen²⁵ classifies design problem a unique type of problem and as the most complex and ill structured problem encountered in practice. He points out that solving a design problem requires designers structure the problem by defining the nature of the artifact that will satisfy the ill-defined requirement.

Method of design

Research shows that design is a systematic process¹⁶, in which designers have to generate, evaluate and specify the design concepts. The design process is consisted of distinct stages. For example, in the stage model used by Adams^{1, 2, 3, 4}, engineering design is broken into eight stages: problem definition, gathering information, generating ideas, modeling, feasibility, evaluation, decision and communicating. This kind of systematic approach might help designers, especially student designers, as Radcliffe and Lee³⁹ find that the degrees to which students follow structured design process correlates positively with the quality or the effectiveness of design.

However, in practice, designers do not strictly follow this stage model. Fricke's^{18, 19} research suggests that designers following a “flexible –methodical procedure”¹³ (p91) tend to produce better solutions. It is found that designers who follow a fairly logical procedure produce better solutions, compared with designers who rigidly follow the systematic approach. This kind of flexibility could be diverse and unique, depending on individual designer. For example, studies show that some designers may skip one phase and go directly to the next stage and the whole design process can be different for designers because of their preference, education background, etc²².

This study integrates a framework of design process²³ and an existing operational model of a design process²⁹, 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', as both of them agree that designers construct the problem first, generate ideas and then work on details.

Among these stages, concept generation has been regarded as one of most important³⁶. Concept generation is also closely related with creativity design as designers often

come up with novel ideas in this stage³⁴. As previous studies reveal student designers have a difficult time in the concept generation stage^{14,24}, we are interested in exploring what kind of difficulties and problems students meet in the concept generation stages.

2) Paper sketches 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^{35, 31}. One of the widely used external representations would be paper sketches, which help designers construct their thoughts⁴³, recognize emerging features^{35, 7} and generate more solutions⁴².

Cardella, Atman & Adams¹¹ study how engineering student designers use external representations in design activities. They found that sketching, one of the main representational activities, play an active role in the design process. They also observe that students sketch a lot in the problem scoping stage, which resonates with Römer, Leinart and Sachse's³⁷ finding that sketching supports problem formulation. This is also noticed by Cross¹⁰, who points out that one key feature of paper sketches is that they assist problems structuring. Studies in graphic design further demonstrate that paper sketches play a big role in the early stage of design. For example, Stone & Cassidy's⁴² research shows that graphic designers who use paper-based sketches in the preliminary graphic design decision making stage produce more solutions than those who use digital working.

So why are paper sketches so essential in the design process, especially in the early stage? By studying architectural designers' sketches, Cross¹⁰ suggests that paper sketches can help designers to consider many aspects together at one time. In addition, Cross summarizes that "sketches enable designers to handle different levels of abstraction simultaneously." (p37) Especially, in the early stages of design, paper sketches provide designers a chance to move freely between different levels of details, from the overall concept to the detailed aspects of the implementation. The ambiguity and uncertainty in sketches allows room for imagination and creativity. As the design develops, more structured forms of representation appear, which are very likely to become the prototype of the final design product because they help designers recognize emergent features and properties of the solution concepts¹⁰. This whole process of sketching is regarded as a dialogue between the designer and what is designed^{21, 40, 35}.

3) 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. Several studies show that computers can be helpful to designers. LeCuyer²⁷ compares two expert architects' approach to

the creative use of computers in design. In her study, one of the experts uses computer-generated forms as the starting point while the other uses computer in design development. Computer helps both designers create good design product. Won's⁴⁶ analysis of two designer's working methods also indicate that working on computers could be beneficial to designers as it provides designers immediate visualized feedback

The reason why computers could assist design is further explained by Madrazo³³, who claims that digital visual representations can better support visual thinking. This is also supported by Marx³², who points out that intensive visualization and immediate feedback in computers enable the designer to generate image in his/her mind more frequently.

However, not all researchers believe computer is a useful tool for designers. For example, Stone & Cassidy⁴² 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 could be that the physical act of drawing enables designers to reexamine and reinterpret their thinking, which is lack in computer-aided-design. Fish & Scrivener¹⁷ discuss why computer is not that powerful in assisting design. They believe that computer systems fail to represent the implicit structure which would help designers to scope the problem. And this forces designers to provide detailed information too early in the design process, which may lead to premature decisions and prevent designers from considering alternatives.

As it is shown above, both paper sketches and computer have some advantages and each 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.

4) Student designers

Students designer are different from expert designers. As Dreyfus and Dreyfus¹⁵ identified, novices go through progressive stages from novice, advanced beginner, competent, proficient and finally become an expert. The literature provides us with evidence-based presumptions when dealing with student designers. In general, experts perform better than novices in a number of aspects: For example, both Batra & Davis⁶ and Crismond⁹'s work, which investigate expertise in design across different domains, find that experts tend to recognize similarities among situations and make connections between their works. Cross's⁸ study summarizes most of the vital features of expert performance, like the ability to form abstract conceptualizations and decompose problems explicitly. An additional summary of characteristics of expertise was

conducted by Farrington-Darby and Wilson²⁰: Experts are inclined to perceive large meaningful patterns, encode new information quickly, adapt decision strategies to changing task conditions, possess the ability to make more schema-driven analogies and generate a holistic understanding of problem etc.

Research on student designers tells us that students use sketches a lot in their design¹¹ and sketches help them generate more solutions⁴². However, most of the past studies are based on the observation. Not many of them ask students' view about how sketches or computer helps them design. This research tends to fill this gap by using a survey and semi-structured interview to explore students' attitude towards using sketches and computer in design. Besides, we explore student designers' advantages and disadvantages in graphic design, which contributes to the literature of novice-expert difference.

Methods:

The study was conducted in a computer graphic program of a large Midwestern university in the US. The participants were recruited from two 2D commercial graphic design courses. CG01 is an introductory course for freshmen to acquire and implement basic design principles for visual communication; CG02 is an advanced course for students in the 2nd year or above, to design, create and prepare documents for commercial printing (see detailed information in Table 1).

Courses	Participants in survey	Participants in interview	Production
CG01	46 (7 females; 39 males)	28 (6 females; 22 males)	Practice basic design elements, principles, composition and typography to communicate visually by solving exercise problems and designing projects like identity logo, flyer, calendar, and postcard. Program: In Design
CG02	19 (8 females; 11males)	17 (6 females; 11 males)	Design single and multiple- page documents for business, advertising such as identities, flyers, brochures, forms, catalogs, newsletters and booklets. Program: In Design
Total	65	45	

Table 1

We implemented a two-phase, mixed method study using a survey followed by in-depth interviews and observations.

The survey we designed consisted of 71 items measuring various problems students may meet in five different stages of design (matched to the framework discussed above): 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”. In this study, we are only interested in questions related with the use of sketches and computers in design.

The semi-structured interviews following the survey allowed us a better understanding of why and how sketches or computer help students with their design.

Quantitative data analysis and discussion

1) What difficulties student designers encounter in design and concept generation stage?

The descriptive statistics in figure 1 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 much greater. Besides, among the top five difficult problems students meet in the whole design process, three of them belong to stage 2 (Figure 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. Therefore it is further demonstrated that students have a difficult time in generating ideas and concepts. These findings are supported by previous studies on student designers. For example, Condoor et al¹⁴ note that students are lack of ability to generate alternatives and they exhibit design fixation. Hokanson’s²⁴ study of student designers also shows that “Getting the ideas and refining them is the hardest part” (p82).

1) What role does sketching play in design?

Previous literature review suggests sketching is an effective tool for designers, particularly in the early stage^{35, 7}. Our analysis (Table 2) 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. This correlation is especially significant in the concept generation stage.

However, analysis of strategy students prefer to use in the concept generation stage (Table 3) shows that students do not use paper sketches a lot as we expect. 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, which means students’ attitude towards using sketches is neutral.

In sum, quantitative data analysis indicates that paper sketches are helpful for students in the concept generation stage but are not widely used. Because computers are also provided in this study as a design tool, we assume the reason why sketching is not so popular is that students have an alternative choice- computers. Therefore, in the interview session, we further explore students' preference on design tools and how computers and paper sketches help them design.

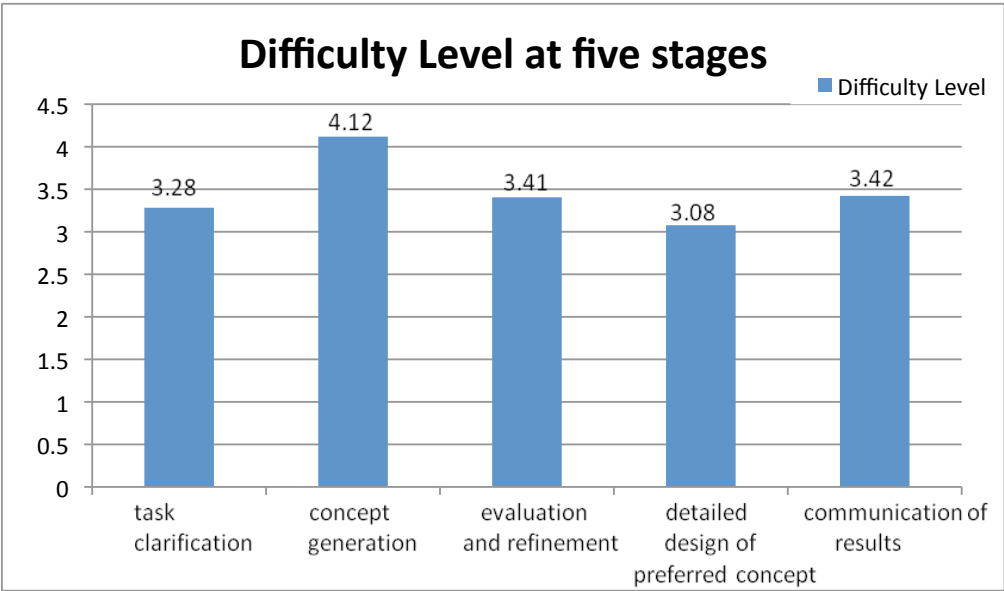


Fig 1

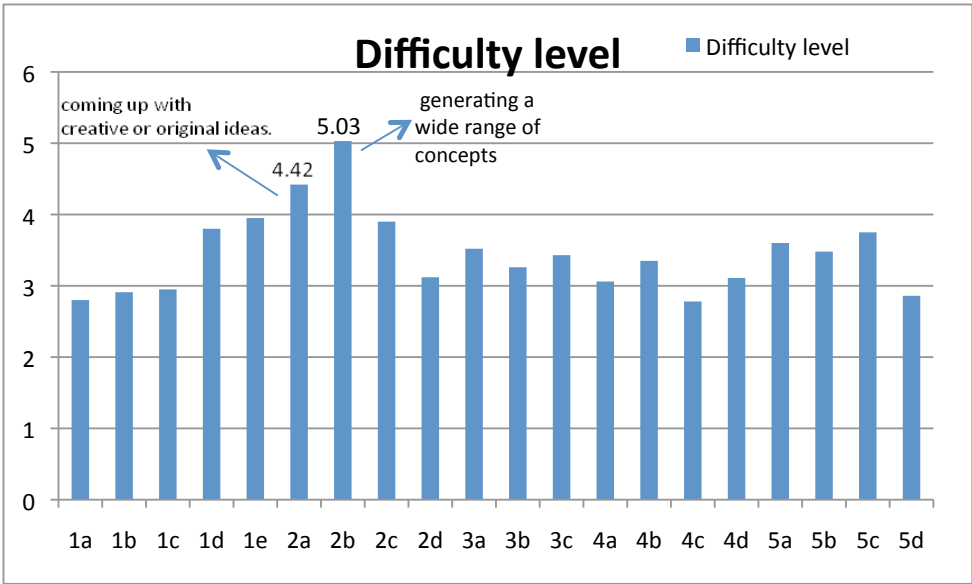


Fig 2

		stage1	stage2	stage3	stage4	stage5
I sketch and take notes by hands to analyze problems	Pearson Correlation	-.279*	-.375**	-.105	-.212	-.075
	Sig. (2-tailed)	.024	.002	.404	.090	.554
	N	65	65	65	65	65

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

Table 2

	Strategy	Useful
	1h	5.05
	1i	5.69
	1j	3.58
	1k	4.86
	1l	4.98
Jotting down ideas on papers	1m	4.65
	1n	4.72
	2g	4.72
	2h	3.74
	2i	4.75
	2j	4.38
	2k	5
	2l	4.92
	2m	4.95
	3f	5.05
Drawing varied versions of sketches for the final selection	3h	5.28
	3i	5.19
	3j	4.06
	4g	4.1
	4h	4.91
	4i	4.91
	4j	3.78
	4k	3.85
	4l	5.45
	4m	3.77
	5g	5.42
	5h	3.55
	5i	4.58
	5j	3.8
	5k	3.97

Table 3

Qualitative data analysis and discussion

1) Which tool do student designers prefer to use when they are in the concept generation stage of design? How do computers and 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 show that while a number of students find this sketch-first method to be helpful, many others prefer directly working on computers.

Students who liked to sketch first 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”.

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 indicates that the physical act of drawing enables designers to reexamine and reinterpret their thinking⁴².

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 that sketching provides external memory to aid the designers⁴⁴.

In contrast, students who preferred directly 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 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”.

Most 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 effect”. This finding ties back to Marx’s³² idea that the intensive visualization and immediate feedback provided by computers prompt students generate ideas. By using computers, students can play with real objects which help them better visualize design. This may be particularly true when design is complex. For instance, one student mentioned “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”. 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 disadvantage, 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 does indicate that one of the reasons why computer is not that powerful is that it forces designers to provide detailed information too early in the design process, which may lead to premature decisions and prevent designers from considering alternatives¹⁷.

In sum, as it is mentioned by students, sketching is a quick way to put down and visualize their initial ideas. Paper sketches help students get a general and basic understanding of their design. At the same time, designing on computers enables students to work on more details. Students could see real objects and use software to try different effects. That’s why many students feel their design on computers is more similar to the final product.

2) 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^{35, 27, 46} both indicate that sketches and computers are important tools to help students generating 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's²⁶ study points out, the traditional view of freehand sketching as the primary conceptual tool is challenged in this digital age. Nearly half of the participants prefer directly working on computers. This indicates that computers as a design tool are becoming powerful and helpful for students.

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

Compared with expert designers, novices are incompetent in some aspects and still have room for improvement.

One distinct disadvantage for novice designers that we noticed in this study is their lack of computer / sketching skills. This could be an obstacle which prevents students from working on computers/sketching. For example, Stone & Cassidy⁴² believes the technique challenge posed by using computers makes computers less helpful for designers. 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 able to mentally form abstract conceptualizations⁸.

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.

Conclusion

This research shows that sketching and computer as design tools help student generate ideas in the early stage of design. Each tool has its own advantages. In summary, sketching is a quick way to put down and visualize initial ideas. Paper sketches help students get a general and basic understanding of their design. However, sketching may be time consuming and could be nightmare for students who are not good at drawing. Designing 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 sketching does. For instructors who teach design, it may be better to help students recognize both the benefits and disadvantages of using sketches and computers before starting the design. Instead of forcing students to use one tool or both, a reasonable way would be to let students

decide which tool is more suitable for them.

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