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The Influence of Expertise upon the Designer's Approach to Studio Practice and Tool Use

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Abstract: Industrial design is characterized by the embodiment of design intentions. From conceptualization through to design specification, the designer employs a variety of design tools to externalize and develop design solutions to often ill-defined design problems. Surveys of student and practicing designers synthesise existing theoretical and empirical studies of design practice to analyse designer attitudes towards tool use and effectiveness. The survey studies illustrate the influence of expertise upon the designer's attitudes towards tool use during studio practice. Results indicate a relationship between limited experience and the designer's perceptions of and approaches to iterative exploration and design divergence. The use of certain designerly tools appear to compound a tendency for design convergence and fixation.

KEYWORDS: industrial design; design tools; design activity; design expertise

Introduction

Industrial designers are futurists, embodying and communicating a vision of the possible or ‘yet-to-be’ (Nelson and Stolterman, 2003). Since the activity of industrial design is

often separate from industrial manufacture, a key concern is the generation, development and specification of design intent prior to production (Cross, 2007). To facilitate the exploration of design solutions, their development and final specification, the designer will employ a variety of design tools to embody and represent design in-tentions as sketches, drawings, illustrations, models and prototypes of varying degrees of detail and fidelity.

The term industrial design may cover a wide variety of artefacts, from consumer products, one-off works to industrial plant and equipment products (Rodgers and Milton, 2011). While in reality these distinctions merge and overlap in the design of the material world (Dant, 1999), it is the knowledge and expertise employed in the design and development of consumer products that this study focuses upon. Even within this category a wide-ranging number of designed artefacts can be identified, from lighting to personal computers and automotive design. The artefact type will no doubt have implications for the ways in which design activity is engaged, the ways design intentions are communicated to other stakeholders and the kinds of design tools employed in support of studio practice. However, although the authors acknowledge the implications of the type of artefact being designed on the designer’s approach to design activity, understanding these implications is not the purpose of this investigation. Instead, the study explores the role design expertise plays in informing perceptions of tools of design representation and their use in support of practice. To this end we employ the term industrial design as a means to describe design practices aimed at the design and development of industrially manufactured consumer products. While admitting the influence of design discipline and product type upon design activity and tool use, the study adopts a more general notion of design expertise (Lawson and Dorst, 2009) to explore its role in informing attitudes and perceptions towards the use of design tools.

Designers use a variety of tools and processes to embody and rep-resent design proposals during practice, including various sketches, drawings, models and prototypes (Pei *et al*, 2011). These tools support the generation and evolution of design ideas from an open, conceptual phase of the design process to the constrained detailed specification of intent prior to manufacture (Ulrich and Eppinger, 2003). These design embodiments, constructed through the use of design tools, constitute the designer's attempt to explore and com-municate intentions towards design solutions (Visser, 2006). Through the generation of these embodiments, the industrial designer is bet-ter able to explore often ill-defined design problems (Cross, 2000) as well as communicate design intentions to stakeholders.

Although industrial design practice is concerned with convergence towards a final specification of design intent (Cross, 2000), design activity will alternate between convergence and periods of iterative, divergent exploration. Figure 1 illustrates a generic model of the design process based upon divergent/convergent design activity, as described by Cross (2000). Supporting the exploration of solution ideas and their communication to stakeholders during a process of design, the designer's embodiment of design intentions is critical.

The use of sketching and computer-aided design (CAD) tools has received significant attention in research interested in develop-ing an understanding how they support design practice (Bilda and Demirkan, 2003; Fish, 2004; Goel, 1995; Jonson, 2005). However, there is little empirical work to describe relationships between the designer's approach to tool use and the influence this has upon

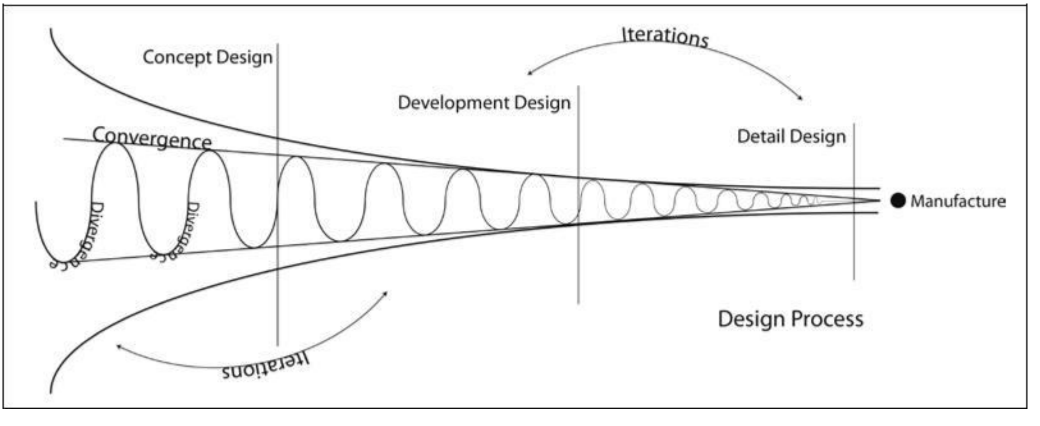

Figure 1
Generic model of industrial design process: divergent concept design to convergent detail design.

design activity. A notable exception is Stolterman *et al*'s (2008) framework for studying how practising designers actually view and evaluate tools. Using a small sample of designers, and evoking Heidegger's (2008) notions of equipment and the tool as ready-to-hand, Stolterman *et al* (2008) explores design tools in terms of the purpose of design practice; the activity required to achieve that purpose; and the tool(s) seen as best supporting the design activity. The study concluded that design experience and idiosyncrasy is influential in tool choice and use.

Tools for Design Embodiment

Baber (2003) refers to tool use as allowing, 'their user to act upon their environment, in order to achieve specific goals'. In a similar way to Stolterman *et al*'s (2008) Tool-In-Use model, Baber (2003) suggests tools are used as part of a relational co-dependent activity which includes the tool user, the tool and the purpose of activity. Visser (2006) uses the term 'construction' to describe the activity of making design representations, with the designer employing tools to augment this construction.

This study defines the design tool, sketches, drawings, models and prototypes for example, as the media through which design intentions are embodied and represented. These tools are employed and manipulated in various ways in response to the designer's own approach to and understanding of tool use. For example, the tool may be used to support the exploration of the design problem and the generation of solution proposals. It may be used to develop and refine design concepts or as a way to communicate intent to stakeholders at various stages in the design process. Both the tool-in-hand (the design tool used in support of a design action) and the designer's own idiosyncratic approaches to its use will influence the nature of design embodiment and the character of design activity (Cross, 2007).

Universal Characteristics of Design Activity

A large body of previous work has explored the designer's use of sketching during concept design (Jonson, 2002; McGown *et al*, 1998; Rodgers *et al*, 2000; Tovey and Owen, 2000; Tovey *et al*, 2003; Verstijnen *et al*, 1998, for example); CAD's use during the early stages of design practice (Bilda and Demirkan, 2003; Goel, 1995; Jonson, 2005; Tovey and Owen, 2000; Robertson and Radcliffe, 2007); and the use of hybrid tools to support human–computer interaction during design activity (Dorta *et al*, 2008; Dorish, 2001; Hornecker, 2007; Evans *et al*, 2005; Sener and Wormald, 2008).

From this body of existing research, the study identifies and synthesizes five Universal Characteristics of Design Activity (UCDA). These UCDAs were then employed in the design of survey questions to explore designer attitudes towards their use of design tools during studio practice. Table 1 presents these five UCDAs. The columns

Table 1 Universal Characteristics of Design Activity (UCDAs)

UCDA	*Descriptors of UCDA*	*References to UCDA*	
1. Reflection-in/ on-Action	The design activity is characterized by reflection-in-action, a conversation with the situation and/or communication of design intent	Dorta *et al* (2008)	Self-reflective mode
		Schön (1991)	Representation, analysis, emergence
		Goldschmidt (1997)	Dialogue with self
		Jonson (2005)	I-representations
2. Level of Ambiguity	To what extent the activity is characterized by ambiguity in both intention and design representation	Fish (2004)	Vagueness
		Goldschmidt (2004)	Unstructured nature
		Goel (1995)	Ambiguity/density
		Visser (2006)	Unspecific
3.Transformational Ability	To what extent the design activity is characterized by the lateral and or vertical transformation of design intentions	Goel (1995)	Transformation
		Visser (2006)	Duplicate, add, detail, concretize, modify, revolutionize
4. Level of Detail	To what extent the design activity engages specific detail in the exploration of design ideas	Brereton (2004)	Kinds of information available
		Visser (2006)	Precision
		Goldschmidt (1997)	Less/more specific
5. Level of Commitment	How committed the design activity appears to be to the proposal of design solutions	Goel (1995)	Early crystallization/ completeness
		Pipes (2007)	More/less committed
		Powell (1990)	Commitment
		Tovey *et al* (2003)	Uncommitted/ more committed

to the left show the terms used to describe the UCDA and short descriptors of each characteristic. The columns to the right present where within the existing literature the UCDA were identified and the terms used at source.

The five UCDAs were employed in the design of survey questions to generate data relating to designer attitudes towards their use of ten design tools. These design tools were identified from a literature review as often used to support industrial design practice (Eissen and Steur, 2011; Haller and Cullen, 2004; Hudson, 2008; Pei *et al*, 2011; Pipes 2007; Rodgers and Milton, 2011).

Design Expertise

The Dreyfus and Dreyfus (1986) model of skills acquisition proposes a generic approach to the development of skills and knowledge based on six stages: novice, advanced beginner, competent, expert, master and visionary. Lawson and Dorst (2009) applied this model to explore the skilled representation of design intentions through drawing and sketching. Their work considered a designer who is less able to represent ideas effectively as being, 'severely handicapped and unlikely to be able to reach an advanced level of expertise' (Lawson and Dorst, 2009). Liikkanen and Perttula (2009) suggest design students may be classified as 'advanced beginners' and that practitioners may be considered 'expert' once a minimum of three years professional experience is reached. While this is an informed generalization, Liikkanen and Perttula (2009) acknowledged that individual designer's progress in their various skills at different rates and in different ways. This notwithstanding, the Dreyfus and Dreyfus model (1986) was seen as a means to identify and classify the two sample groups of survey respondents.

Research Aims

The investigation aimed to identify attitude trends towards tool use from substantive samples of student and more experienced practising industrial designers, rather than to investigate individual skills acquisition. The use of the generic terms 'advanced beginner' (students) and 'expert' (practitioner) served to illustrate the different levels of experience the two samples brought to their choice and use of design tools in support of design activity. The study aimed to explore designer attitudes with the objective of contributing to an understanding of design expertise as it relates to how tools are perceived and how these perceptions then influence the designers understanding of and approach to tool use. With these aims in mind, the study addresses the following research questions:

1. What differences exist between expert and less experienced designers in their attitudes towards and perceptions of tool effec-tiveness and use during studio practice?
2. How do these differences then influence the designers under-standing of and approached to tool use in support of design activity?

The purpose of this investigation was to explore how expertise influences the designers' attitudes towards and perceptions of tool use. To then consider the implications of any findings for contributing to an understanding of the relationship between design expertise, tool choice and use.

Research Methods

The study uses the survey as research method. This was adopted in preference to other commonly used design research methods such as observation and protocol analysis as it afforded sampling of a large number of participants in a relatively short length of time (Alreck and Settle, 2004). The use of surveys was seen as a pragmatic means to generate a relatively large volume of data, suppressing idiosyncratic use in favour of the identification of attitude trends. The UCDAs (Table 1) were employed in the design of survey questions relating to ten design tools. As such, the survey study and design of the survey as research instrument, was grounded by existing principles that inform contemporary understanding of the character of tool use during design activity.

Survey Samples

The surveys generated a total of 116 usable design practitioner responses and 106 design student responses. The practitioners had been active in professional practice for three years or more and the students were all final-year undergraduates. Data gathered at the start of the survey related to respondent attributes indicated that a majority of the practitioner sample were drawn from the discipline of industrial/product design (Table 2).

The student sample was taken at the *New Designers Exhibition* (2010) and from Loughborough University's BA Industrial Design course, third-year cohort (2010). This sampling technique was adopted due to convenience in accessing the student sample (Table 3).

Practitioner participants were sourced from the design firm listings of the industrial design online magazine and design resource *Core77* (2012) and directed to complete an online survey. The students were given a paper copy of the same survey which employed identical questions to the practitioner survey. A response rate of 20 per cent was achieved from the practitioners and 98 per cent from the students. The Loughborough sample and that taken at the *New Designers Exhibition* were completed as a handout and then

Table 2 Practitioner sample by discipline

Design discipline	*Number of respondents*
Industrial Design	55
Product Design	37
Engineering Design	6
Packaging Design	2
Design Management	2
Automotive/Transportation Design	2
Interior Design	2
Interaction Design	2
Graphic Design	1
Other	4
*Fail to provide a response to question	3
Total responses: 116	

Table 3 Sample of design students

Location of survey	*No. of students*	*Title of course*	*Level of expertise*
New Designers Exhibition	62	Various courses throughout UK using ‘Product’, ‘Industrial’, ‘Transport’ in course title (graduating)	Advanced beginner
Loughborough University, Faculty of Design and Technology	44	BA(Hons) In Industrial Design (third year)	Advanced beginner
Total student sample: 106			

collected after completion. The difference in response rates can be accounted for by the method of distribution (Bryman, 2008). That is, the student surveys were distributed, completed and collected by the authors. It must also be noted that, due to the online nature of the practitioner survey, the practitioner sample may to some extent have a bias towards those with an interest in the research area. Finally, the student sample was taken from one design programme and one student design exhibition. As such, the responses provided by the student participants from the single design course may have been influenced by the particular curriculum and education the programme provides. This has implications for generalizing results as an indication of the perceptions and attitudes of all novice designers.

Survey Design

The practitioner survey was divided into two sections. The first section consisted of four questions designed to gather information on the respondents’ profile, i.e. size of company; academic and vocational qualifications; design discipline and number of years’ experience in practice. Because the survey of design practitioners was undertaken online, this information was required to identify the attributes of the respondent practitioners. As the researcher was aware of the students’ level of experience as finalist student designers, these initial questions were omitted from the student survey.

Both student and practitioner surveys employed an identical set of eight, five-item Likert-scale questions (Bryman, 2008). The eight questions were designed to gather data on the student and practi-tioner attitudes towards design activity and their use of design tools. The survey questions asked respondents to rate ten design tools in terms of the tools’ ability to support UCDAs (see Table 1). Table 4 presents the eights questions asked (left) along with the UCDAs each question was designed to measure (right).

Table 4 Eight Likert-scale survey questions and UCDAs measured

Eight questions to measure attitudes towards five UCDAs	*UCDA measured*
Q1. The design tools listed below are useful for representing the engineering detail of design ideas. Do you agree or disagree?	UCDA: Level of Detail
Q2. The design tools listed below are useful for representing the artistic/ creative form of design ideas. Do you agree or disagree?	UCDA: Level of Detail
Q3. The design tools listed below are useful for representing design ideas in a more constrained, unambiguous way. Do you agree or disagree?	UCDA: Level of Ambiguity
Q4. The design tools below are most useful for design work that can move easily between design ideas (Lateral Transformations). Do you agree or disagree?	UCDA: Transformational Ability
Q5. The design tools below are most useful for design work on variations of one or the same design idea (Vertical Transformations). Do you agree or disagree?	UCDA: Transformational Ability
Q6. The design tools below: Communicate a high Level of Commitment to design ideas. Do you agree or disagree?	UCDA: Level of Commitment
Q7. The design tools below are more useful for communicating design intentions to others. Do you agree or disagree?	UCDA: Reflection-in/on-Action
Q8. The design tools below aid reflection and the dynamic generation and evolution of design ideas. Do you agree or disagree?	UCDA: Reflection-in/on-Action

Responses to the eight questions were captured using five-item Likert scales (Bryman, 2008) whereby the following response values were given:

Strongly Agree (+2); Agree (+1); Neutral (0); Disagree (-1); Strongly Disagree (-2)

By way of example, Figure 2 illustrates a survey page from the student survey designed to gather data on attitudes towards the design tool: 3D CAD.

Students were required to indicate attitudes towards 3D CAD in terms of its ability to support UCDAs through the eight Likert-scale questions (Table 4). Below the questions, images were used to provide an example of the type of design tool and design embodi-ment made through the use of the tool (design development models, presentation models).

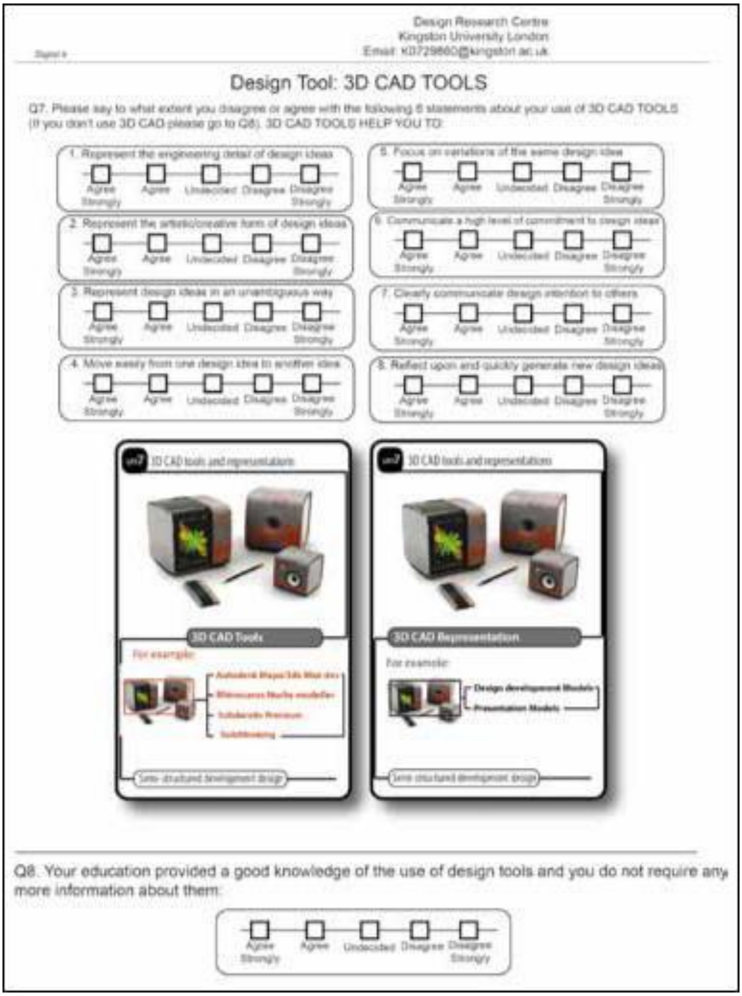

Figure 2
Example student survey page relating to 3D CAD. Courtesy of Loughborough University.

Results

Results indicated that the designer's experience had an influence upon their attitudes towards and perceptions of tool use in support of design activity. This observation was achieved through the examination of practitioner and student attitudes towards various design tools in terms of the participants' perceptions of the tools' ability to support the five UCDAs. The following sections present a selection of the findings from the survey study. The presentation of results focuses upon the implications for an understanding of the relationship between design expertise and the designer's approach to tool use (see Self 2012 for complete set of survey results).

Designer Attitudes towards Hand Sketching

Figure 3 illustrates survey findings for practitioner and student responses to the eight attitude questions presented in Table 4. All

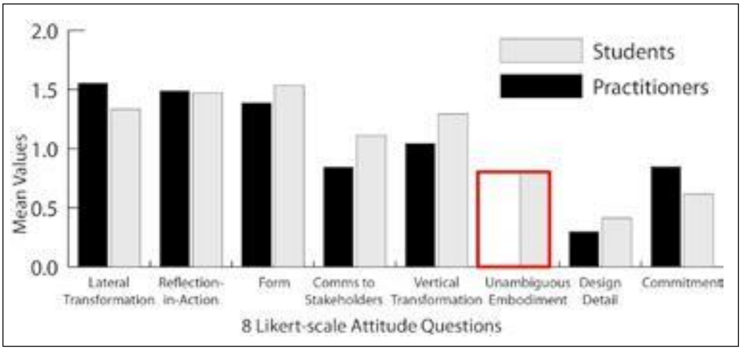

Figure 3
Responses to eight attitude questions on the character of hand sketching tools.

results are shown as mean values, i.e. the coded sum (Likert-scale questions were assigned a code form -2 strongly disagree to +2 strongly agree) of responses to each of the eight questions divided by the number of respondents (Bryman, 2008).

In terms of the use of hand sketching, practitioner and student results were similar across the eight Likert-scale questions bar one: sketching's ability to support the unambiguous embodiment of de-sign intentions (Figure 3, in thick outline).

Figure 4 illustrates practitioner and student responses to sketch-ing's ability to support unambiguity across the five items in the Likert scale (horizontal axis). The vertical axis shows the distribution of responses as percentages of response to each item on the scale.

A majority of student designers (62 per cent) recorded agreed when asked of sketching's ability to support unambiguous design embodiment. In contrast, a third of practitioners (33 per cent) re-corded a neutral response and a further third (32 per cent) disagreed when asked the same question (Figure 4, in thick outline).

The results presented in Figures 3 and 4 are indicative of contrast-ing attitudes towards hand sketching in terms of its ability to support unambiguous design embodiment. The student results suggested their greater tendency to consider sketching as an unambiguous medium through which design may be represented, compared to the practitioners' view of sketching as a tool that supports more ambiguity in design embodiment. This may indicate how attitudes

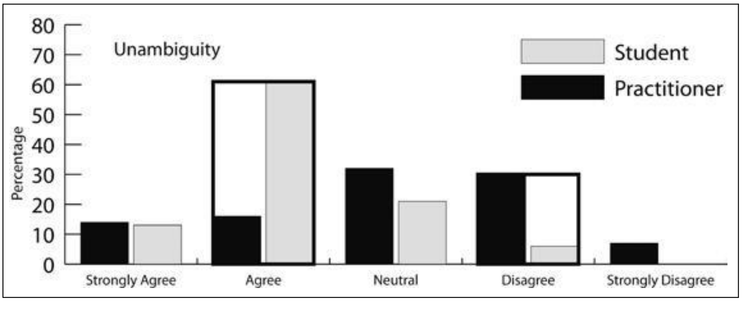

Figure 4
Responses to the question asking: Hand sketching is useful for representing design ideas in an unambiguous way.

towards sketching differ with experience of practice, with student designers tending to take a more unambiguous approach to design activity when sketching in contrast to the practitioners' more am-biguous embodiment of design intent.

Attitudes towards Sketch Modelling Tools

Figure 5 illustrates student and practitioner responses to eight Likert-scale questions relating to the design tool sketch modelling.

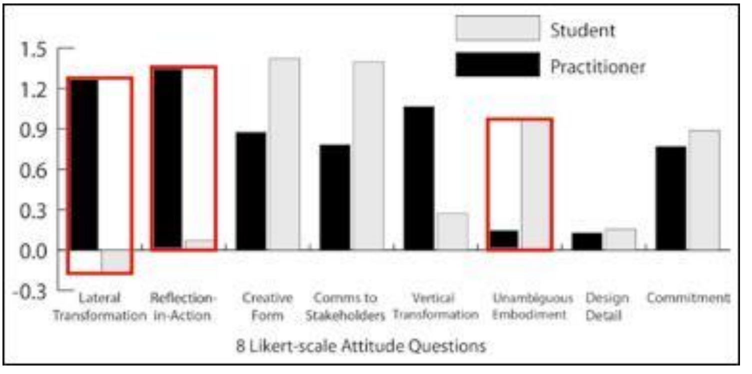

Figure 5
Responses to eight attitude questions on the character of sketch modelling.

In terms of sketch modelling, students and practitioners regis-tered strongly contrasting responses across four of the eight Likert-scale questions: lateral transformations, reflection-in-action, vertical transformation and unambiguity (Figure 5).

Figure 6 illustrates responses for designer attitudes towards sketch modelling's ability to support lateral transformations (the movement between one design idea and a new idea).

The practitioner sample registered agreement (40 per cent) or strong agreement (45 per cent) when asked of sketch modelling's ability to support lateral transformations. In contrast, the student sample registered more confounding responses to the same ques-tion (28 per cent agree, 39 per cent disagree). Confounding stu-dent responses and more positive practitioner attitudes were also

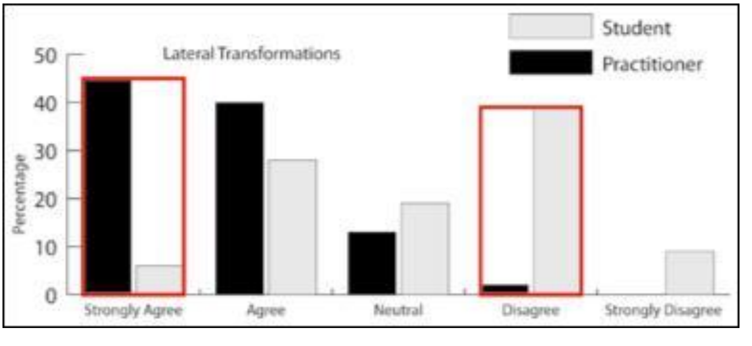

Figure 6
Responses to the question asking: Sketch modelling is useful for design work that can move easily between design ideas (lateral transformations)

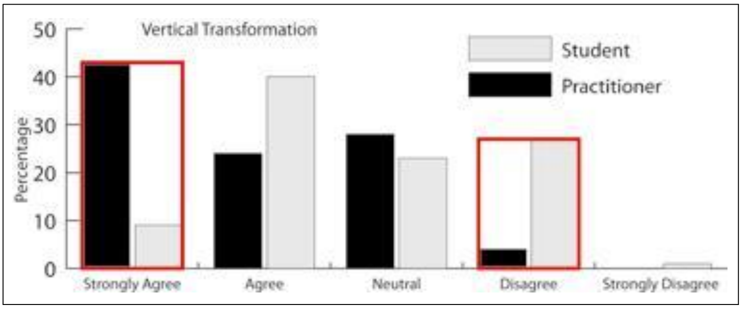

Figure 7
Responses to the question asking: Sketch modelling is useful for design work on variations of the same design idea (Vertical Transformations).

identified- in response to sketch modelling’s ability to support vertical transformations (Figure 7).

A significant number of practitioners recorded strongly agree (43 per cent) with a further 24 per cent registering agree and 28 per cent recording a neutral response when asked of sketch modelling’s ability to support vertical transformations. The student results indicated a greater difference in opinion across the five items of the Likert scale with 40 per cent agreeing and 27 per cent disagreeing.

Results indicated a tendency for a proportion of the student sample to perceive sketch modelling as a tool less suited to the support of lateral or vertical transformations during design activity. In contrast, practitioner results indicated they were more inclined to see sketch modelling as effective in supporting both modes of transformation.

The results may indicate the nature of the relationship between design expertise and tool use. With experience the designer’s approach to modelling may be more inclined to result in the vertical and lateral transformation of ideas. Student design activity, however, may tend to be characterized as lacking in transformation with a greater emphasis on fixation. Students, lacking in design experience, may be inclined to take a more convergent approach to the use of sketch modelling as it is employed to support design thinking during conceptual design practice.

Figure 8 illustrates practitioner and student results relating to the question of sketch modelling’s ability to support reflection-in-action (to reflect on one’s own design work; Schön, 1991).

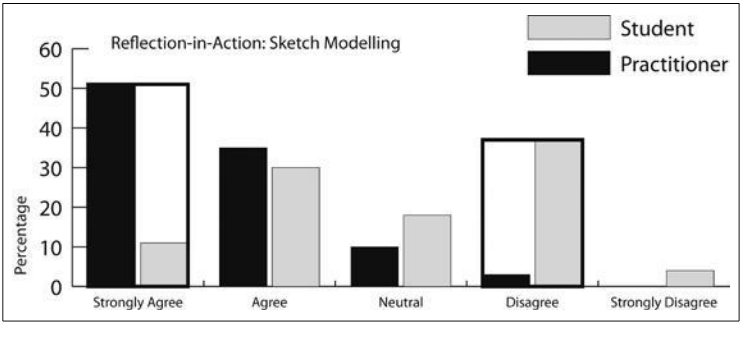

Figure 8
Responses to the question asking: Sketch modelling aids reflection and the generation of design ideas.

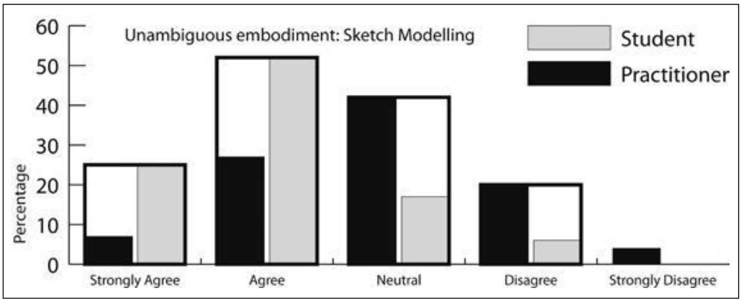

Figure 9
Responses to the question asking: Sketch modelling is useful for representing design ideas in an unambiguous way.

In terms of positive agreement, 35 per cent of the practitioner sample recorded a response of agree and 51 per cent strongly agree when asked of sketch modelling's ability to support reflection-in-action. However, student results indicated confounding attitudes within the sample group (30 per cent agree, 35 per cent disagree).

When asked of sketch modelling's ability to support unambiguous embodiment, the results showed mixed responses in both samples (Figure 9). Of the practitioner sample 42 per cent recorded a neutral response, with 27 per cent registering 'agree' and a further 20 per cent 'disagree'. Student results tended to indicate more positive attitudes (25 per cent strongly agree, 52 per cent agree):

The findings indicated that design students and practitioners hold different perceptions towards sketch modelling's relationship to ambiguity in design embodiment. These differences were most prevalent in attitudes towards those UCDAs associated with diver-gent conceptual design activity (Goel, 1996; Schön, 1991), although practitioner results also indicated more positive attitudes towards vertical transformations.

Results indicate how attitudes towards the role and use of sketch modelling as a tool to support design activity may be influenced by design expertise. The findings suggested practitioners may be more inclined to engage in a design activity characterized by transformations, ambiguity in design embodiment and reflection-in-action when modelling. If this is the case, the results indicate and start to define the nature of the relationship between design expertise and the ways in which experience influences attitudes towards the design tool and so the kinds of design activity employed in the exploration of de-sign intent. Findings indicated the practitioners' approach to design activity, when sketch modelling, as more open to exploration and divergence. In contrast, design students may be less inclined to engage in an explorative or divergent design activity when using sketch modelling, as indicated by more negative responses to UCDAs associated with divergent design activity. Perhaps results relating to the less experienced student designers are an indication of pre-existing tendencies towards earlier convergence and concept fixation. These existing tendencies may then influence the ways in which students use and manipulate some design tools, such as sketch modelling.

Attitudes towards Ambiguous Embodiment

The results indicated different attitudes towards ambiguity in design embodiment between more experienced practitioners and design students across ten design tools. In Figure 10 the horizontal axis presents ten tools; from those most often cited as used to support concept design (Hudson, 2008; Lawson, 2004; Pei *et al*, 2011; Pipes, 2007) (left) to those often associated with detail design (right). The vertical axis illustrates student (grey) and practitioner (black) results as mean values. As previously stated, each response was captured on a Likert scale and coded from +2 to -2 (strongly agree to strongly disagree). The sum total was then divided by the number of respondents to arrive at a mean value for each sample group across ten design tools. These mean values are plotted across the chart (Figure 10) to illustrate the student and practitioner attitudes towards unambiguity in design embodiment across a range of design tools.

Figure 10 indicates a difference in attitudes towards the ability of design tools to support the unambiguous embodiment of design intent. Differences in response were recorded between students and practitioners across a number of design tools: hand sketching, digital sketching, sketch modelling, 3D printing, conventional and digital graphics tools and model making. Divergence in response was most noticeable in results relating to hand and digital sketching and sketch modelling, design tools most often associated with a divergent, conceptual design practice (Cross, 2007; Lawson, 2004; Pei *et al*, 2011). A difference was also seen in results relating to tools associated with detail design (RP and 2D CAD Drawings), with the practitioners tending to consider the tools more effective in support of unambiguous embodiment.

The findings suggest the ways in which design experience may influence design tool use during design activity. When using tools

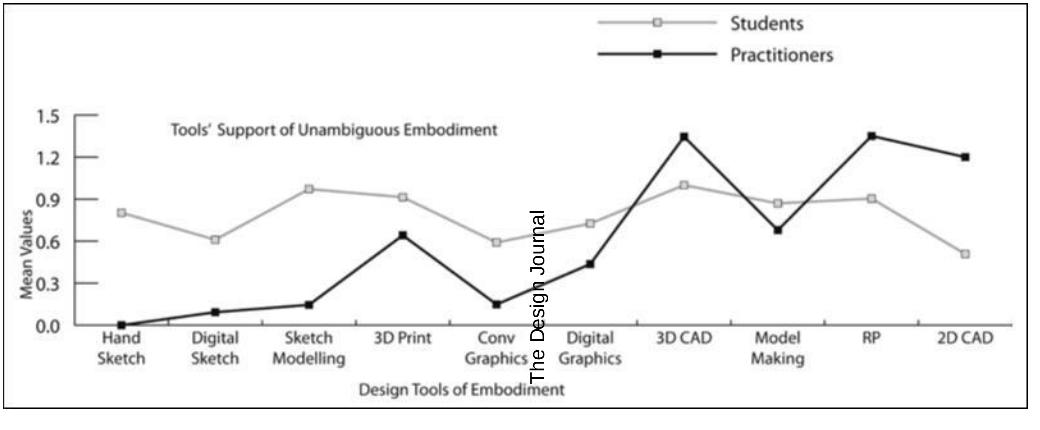

Figure 10
Results for student and practitioner responses to the tools’ support of unambiguous embodiment.

often associated with concept design in support of design conceptualization at an early stage of practice, the approach taken by less experienced designers may err towards the unambiguous embodiment of design intent. In terms of attitudes towards ambigu-ity in design embodiment, the results suggest the designer's level of experience may influence the ways in which the role of ambiguity is perceived. For more experienced designers, this may lead to a more ambiguous and explorative approach to tool use during studio practice. In contrast, student practice may err towards unambiguity with the resulting tendency to converge design intent.

Attitudes towards Lateral Transformations

Figure 11 illustrates results for student and practitioner responses to tool use in support of the lateral transformation of design intent (movement from one design idea to a new idea).

Figure 11 illustrates a clear regression in the positive responses of practitioners towards lateral transformations from those design tools associated with concept design (left) to detail design tools (right). In contrast, the less experienced student designers recorded differing responses across many of the tools included in the survey (Figure 11: sketch modelling, 3D printing, conventional graphics tools, 3D CAD, model making).

As was the case with attitudes towards ambiguity (Figure 10), these results may indicate the nature of the relationship between design experience and tool use during design activity. The student response suggests they may be less inclined to engage in lateral transformations when using various design tools. In contrast, the experienced practitioners recorded more positive responses across many of the tools included in the survey. As with ambiguity in design embodiment, it may be that experienced designers are more inclined to engage design tools through the cannon of a pre-existing tendency towards lateral transformation of design intent during tool use.

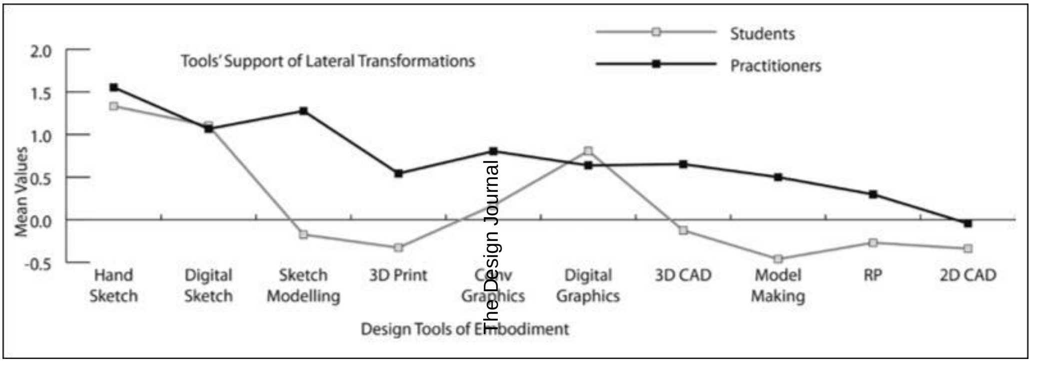

Figure 11
Results for student and practitioner responses to the tools' support of lateral transformation.

Designer Attitudes towards Reflection-in/on-Action

Figure 12 illustrates student and practitioner responses to the design tools’ ability to support design activity characterized by reflection-in/ on-action (the designer’s engagement with and reflection on the embodiment of design ideas; Schön, 1991).

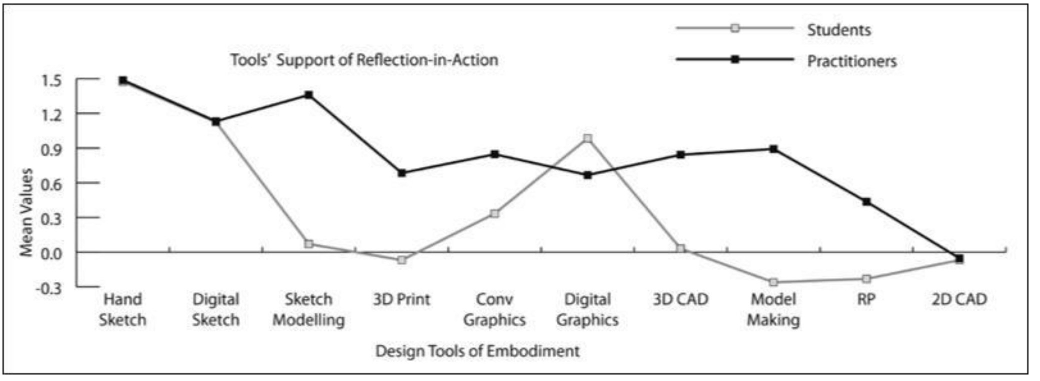

Figure 12
Results for student and practitioner responses to the tools’ support of reflection-in-action.

As with ambiguity in design embodiment and lateral transforma-tions, a difference was identified in responses towards the tools’ abil-ity to support reflection-in-action. The practitioners’ results indicated more positive attitudes compared to the students across the ten design tools. It may be that, as with ambiguity and lateral transfor-mations, there results are indicative of a relationship between design expertise and reflection-in-action (Schön, 1991) during tool use. Less experienced designers may tend to reflect less when engaging certain design tools compared to those with greater experience of practice.

Relationship between Reflection-in/on-Action and Lateral Transformations

Figure 13 illustrates practitioner responses to the two survey ques-tions related to reflection-in-action and lateral transformations. The

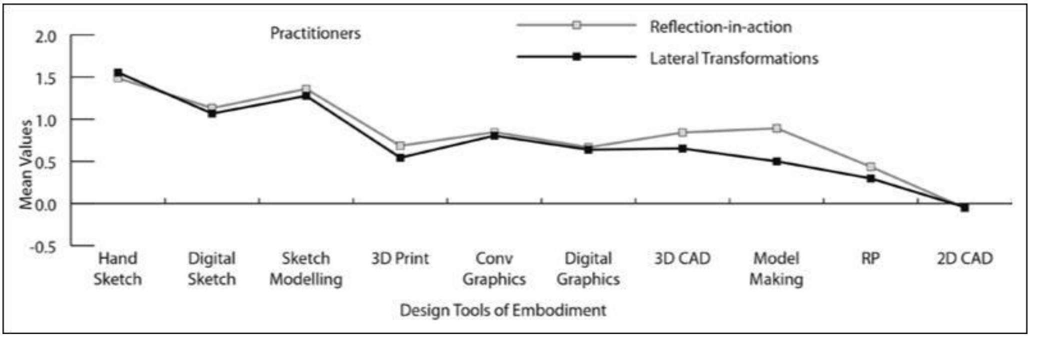

Figure 13
Results for practitioner responses to the tools’ support of reflection-in-action and lateral transformation.

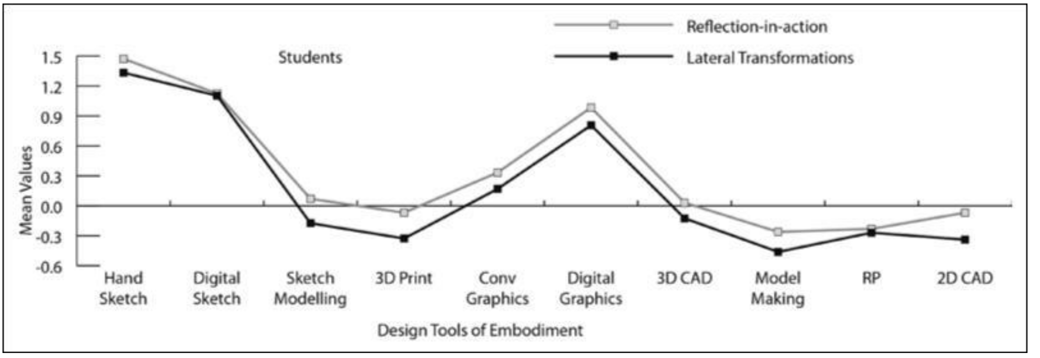

Figure 14
Results for student responses to the tools' support of reflection-in-action and lateral transformation.

findings indicated a relationship between practitioner responses towards reflection-in-action and lateral transformations across the ten tools (Figure 13). The student results also indicated a similar relationship between responses to the same two survey questions (Figure 14).

Both Figure 13 (practitioner results) and Figure 14 (student results) indicate relationships in how the designers responded to questions related to the ten tools' ability to support reflection in action (Schön, 1991) and lateral transformations (Goel, 1995). Both characteristics of design activity have been identified as associated with a more divergent, explorative design practice. Results also indicated a con-trast in responses between the two sample groups in terms of their perceptions of the use of particular design tools: Sketch modelling and 3D printing for example (Figures 13 and 14).

It may be that these findings are indicative of the nature of the relationship between design expertise, tool choice and use. The results suggest the experienced practitioners may be inclined to take a more reflective and divergent approach in their use of many design tools. In contrast, student practice and the ways in which students approach and perceive their own use of tools may tend to result in an activity that errs more readily towards convergence and early fixation.

Discussion

Surveys of design practitioners and design students resulted in the two sample groups recording differing responses for many of the Likert-scale attitude questions included in the survey's design. As previously stated, due to the methods used in student sampling (one design programme and one exhibition), responses may have been influenced by the particular curriculum and education the programme provides. However, although this has implications for the ability to generalize results as an indication of the perceptions of all novice designers, these findings provide valuable initial insights into the relationship between expertise and attitudes towards tool use.

In contrast to this, differences in design expertise within the sample of design practitioners taken from *Core77* may also have influenced their responses to survey questions. However, this study adopts a more generic definition of design expertise (Cross, 2007; Lawson and Dorst, 2009). While acknowledging the particular attributes of individual designers in terms of the type of artefacts they design, education, working environment and culture as all having potential implications for attitudes and perceptions, the study aimed to begin to provide an indication of how design expertise relates to perceptions of tool use. Although there are limitations in the approach taken here in terms of understanding the fine granularity of design expertise, the study's aims were to identify attitude trends. As such, these findings contribute to others aimed at continuing to develop understanding of design knowledge and expertise.

Three UCDA (Universal Characteristics of Design Activity) in particular indicated significant differences in the ways practitioners and students approach and engage design tools in support of their own design activity: ambiguity in design embodiment (Goel, 1995); lateral transformations (to move from one design idea to a new idea; Goel, 1995); and attitudes towards the ability of design tools to support reflection-on-action (Schön, 1991). The practitioner responses suggested more positive attitudes towards ambiguity in design embodiment, transformations and reflection-in-action. In contrast, students' tended to register more negative responses to the same survey questions.

These results are an indication of the nature of the relationship between design expertise and the designer's approach to tool manipulation and use in support of design activity. For example, the experienced practitioners recorded more positive responses to Likert-scale questions that related to ambiguity, transformations and reflection-in-action. In contrast, students, with less design experi-ence, recorded more negative responses to the same questions. This may be indicative of the way in which expertise and experience informs attitudes and perceptions of tool use which then serves to influence design activity. Ambiguity in design representation has been identified as important to a more explorative and divergent design practice (Lawson, 2004; Goel, 1995). The lateral transformation of design ideas has also been linked to divergent design (Goel, 1995), as has the designer's refection-in-action during the construction of design representations (Schön, 1991; Visser, 2006). These findings start to make explicit a link between limited design expertise and the ways in which design divergence is engaged through the use of various design tools. The survey results appear to suggest design students are less inclined to perceive or understand design tools as mediators for engagement with a design activity characterized by ambiguity, transformation and reflection-in-action. In contrast to this, with experience and as the designer's approach to design activity matures, perceptions towards the relationship between tool use, ambiguity, transformation and reflection appears to shift towards positivity. This suggests implications for the nature of design activity in terms of the students' exploration of alternative solutions to a given design problem, for example.

The findings also indicate student use of some tools may compound a tendency to progress design ideas towards detailed speci-fication more quickly, as seen in attitudes towards sketch modelling, 3D printing and 3D CAD's ability to support a design activity de-scribed as ambiguous, reflective and affording transformations. That is to say, the use of these tools is more influential in terms of the speed with which design intentions are moved towards specification and convergence compared to their use by more experienced de-signers. As such, their use may compound a pre-existing tendency towards convergent design.

The significance of these results is in their ability to begin to indicate the nature of the relationship between design expertise and perceptions towards design tool choice and use. The findings sug-gest the ways in which the use of design tools by less experienced designers may be characterized by an approach which results in early convergence and attachment to conceptual ideas. In contrast, the more experienced practitioners may bring a more open and divergent approach to their use of design tools, as indicated in at-titudes towards those characteristics of design activity associated with a divergent conceptual design practice. If this is the case, it is now important to consider the implications these contrasting attitudes have for design activity and what this might then tell us of the ways in which design expertise in knowledge and action is developed.

Conclusions

The research makes a contribution to a more explicit description of the relationship between the designer's perceptions of and ap-proach to the use of design tools during their studio practice and the development of design expertise. The study achieved this through the identification and synthesis of UCDAs. These UCDAs were synthesized in the design of a survey study to explore designer expertise as it relates to perceptions of and attitudes towards design tools. Findings have indicated how design experience and a more explorative approach to design activity and tool use relate. That is, with experience, the designer's perceptions of and approaches to exploration and divergence when using design tools evolve and mature. This then poses some important questions about the relationship between expertise as a catalyst for the evolution of attitudes and perceptions towards tool use and how these evolving perceptions manifest themselves in the activity of developing design ability situated on the continuum between novice and expert. Under what conditions do these perceptions evolve and what implications does this have for the character of design activity itself?

Further investigations are required to both validate these initial findings and to develop understanding of design expertise as it relates to divergent/convergent design activity. These may include investigations that seek to identify and describe the evolving perceptions of designers at various levels of expertise. Further studies may also include investigations aimed at exploring the designer's pragmatic use of design tools in terms of the extent to which evidence of ambiguity, reflection and transformation may be identified in the work of designers of varying levels of design ability. Together with the findings presented here, these further studies will contribute to a more holistic understanding of design expertise and its influence on the kinds of thinking and action deployed during studio practice.

Through the development of an understanding of expert design knowledge and practice, possible pedagogic strategies for fostering a best practice approach to design activity may be considered. The authors propose that such strategies might focus upon developing awareness of the character of professional design activity to provide insight into how design tools may be used in a variety of ways to effectively support the dynamic process of design.

Glossary of Terms

Sketch modelling – the process of creating low fidelity physical design embodiments of concept ideas. Often employing card, paper and other easily formed materials to model concept ideas quickly and relatively easily. Sometimes called quick and dirty prototypes.

Design representation/Design embodiment – the activity of representing design intentions through the embodiment of intent as sketches, drawings, illustrations, models and prototypes of various levels of detail and fidelity

Design fixation – the designer's fixation or attachment to a given design solution as described by Cross (2007).

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