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8. REPRESENTATION IN THE TRANSITION FROM NOVICE TO EXPERT ARCHITECT

INTRODUCTION

This chapter draws on a study of the transition from competence to expertise in architectural design to examine key features of the process and how they are represented. The approach taken is based in cognitive psychology and, in particular, the psychology of problem solving. The study is useful for the purposes of this book given there is evidence that the work of designers (in this case architects) displays evidence of near and far transfer, and of creativity. Of equal importance is the reality that we do not yet have a theoretical model to explain the transition from inexperience to design expertise (Dorst & Reyman, 2004). In terms of representations, given that technology education students engage in learning activities that are represented both verbally and visually, the study has implications for how we research technology learning in school settings.

We know quite a lot about expertise in general and what it looks like in a range of areas (Lajoie, 2003). We know that experts have superior memory for the kinds of information relevant to their domain; have a high level of awareness of what they know and do not know; have superior pattern recognition ability; and they produce solutions much quicker, but spend more time analysing problems before starting; and their knowledge is both deeper and more highly structured that non-experts. However, all of these features are specific to a domain. An expert in chess is not able to use that expertise to solve a design problem.

We also know how to describe expertise in a variety of domains, from electronic troubleshooting (Perez, 1991; Gott, Hall, Pokorny, Dibble, & Glaser, 1992); medical diagnosis (Patell & Groen, 1991; Gott, 1989); nursing (Lajoie, Azevedo, & Fleiszer, 1998); and avionics (Lesgold, Lajoie, Logan, & Eggan, 1990), to name only a few of the studies of expertise. Most of these studies work from a knowledge basis with expertise seen as a function of the knowledge base of the domain.

In a study exploring levels of expertise in design, Dorst and Reymen (2004) argue that we do not yet have any developed model of design expertise. They draw on an expanded version (Dreyfus, 2003) of the Dreyfus and Dreyfus (1986) model that argues for descriptors for seven stages. The 1986 model included novice, advanced beginner, competent, proficient, and expert. The 2003 Dreyfus and Dreyfus model adds master and visionary as two higher levels after expert.

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Dorst and Reymen (2004) argue that the revised Dreyfus and Dreyfus (2003) model is more appropriate for design as it is concerned with the development of skills, rather than being a knowledge-based model. However, the Dreyfus and Dreyfus model is limited by not being tested in any significant way. The assumption underlying the model is also contentious, as it accepts the division between knowledge and skills, which ignores concepts from cognitive psychology that argue that both knowledge and skills can be conceptualised as knowledge, with knowledge (information) constituting declarative knowledge (knowledge that) and skills constituting procedural knowledge (knowledge how) (Newell & Simon, 1972; Anderson, 1993).

One of the dominant theories in cognitive psychology over the last 40 years has been that of the problem space, first proposed by Newell and Simon (1972). The problem space is seen to be a way to represent the kinds of problems humans attempt to solve and the processes they engage in to solve them. The Newell and Simon problem space is argued to consist of three components: the problem state, which represents what is known about the problem at the start; the goal state, which is the solution to the problem; and the search space, which constitutes all the knowledge the problem solver has in memory or can access to solve the problem.

Problem solving is regarded as a process of navigating the search space between problem state and goal state. Navigation of the search space is performed by the deployment of procedural knowledge (knowledge how). However, the research used to validate the problem space model consisted of problems where there were clear descriptors of all aspects of the problem state. Studies involved mathematical problem solving (Newell & Simon, 1972; Anderson, 1993) and games such as the Tower of Hanoi (Kotovsky & Fallside, 1989) that are well-defined at all stages of the process and either have one correct answer or a limited range of solutions.

Designing is considered to be a form of problem solving with a requirement for creativity and innovation. However, the Newell and Simon (1972) model does not provide a useful characterisation for design problems. Unlike mathematical problems, design problems are ill-defined in each of the three aspects of the Newell and Simon model. That is, they have: a generally ill-defined starting point ("We want a house that is light and airy and has a relaxed ambience"); a goal state that is also ill-defined (many clients are able to articulate only some aspects of a potentially appropriate solution); and the search space of design problems contains not only the knowledge that may be in memory or accessible by other means, but also the requirement to be creative, that is, it has the requirement to generate something that is new and cannot be found by a process of search.

Middleton (2002) proposed a revised model of the problem space to accommodate design problems. In Middleton's model the problem state was replaced by the problem zone, to acknowledge that the starting point for design problems was often ill-defined and working out what the problem was constituted the first task in designing. The goal state was replaced by the satisficing zone to acknowledge that in design, solutions are as good as is possible at the time, rather than correct. The search space was replaced by the search and construction space, to acknowledge that the solutions to design problems result from a process of identifying known ideas but also involve the creation of new ideas. One aim of the study reported here was to examine how well the model represents the design thinking of architects at different levels of expertise.

One issue explored in the study and in this chapter is the way knowledge in a domain is represented. Interviews and other forms of verbal data are commonly used in social science research, however, many forms of design use both verbal and visual representations of knowledge and activity. For this reason a methodology was used that collected and analysed both verbal and visual data. The study reported here used a modified form of protocol analysis (Ericsson & Simon, 1993). Protocol analysis, or verbal protocol analysis, is a well-used method for collecting data to examine human cognition. Protocol analysis requires the research participant to verbalise whatever comes into their head while they are engaged in an activity requiring thinking. The verbalisations are not regarded as cognitions directly, but as isomorphs that provide indicators of cognitive activity.

A number of studies examining design processes (see Lloyd & Scott, 1994) have assumed that the verbal protocol analysis method can be used for design even though the activity is not represented only by language. The belief underlying these assumptions is that all relevant data would be contained in the verbal data. In fact, Lloyd and Scott noted the prevailing view in 1994 that any data contained in images would constitute only echoes of the verbal data and thus not add any significant data for analysis.

In an important study, Akin and Lin (1995) sought to test the prevailing assumption with a quite simple experiment. They collected video-taped data of a design activity, using normal protocol analysis techniques (Ericsson & Simon, 1993) with the addition of the visual record of the activity. A copy of the visual data (video with sound removed) was given to one researcher to analyse, while a copy of the verbal data (without the video component) was given to another researcher to analyse. Existing assumptions about visual and verbal data would suggest that all relevant data would come from the verbalisations and analysis of the visual data would not add anything new to the analysis. Akin and Lin found that each researcher was able to predict only 20% of the content of the other data source. The conclusion drawn from the study was that to examine design thinking adequately it was necessary to capture both verbal and visual representation of thinking. Thus, for the study reported here, both verbal and visual data were captured and analysed, separately and then in combination.

RESEARCH QUESTIONS

The study reported in this chapter sought to answer three questions. 1. What does design practice look like at various stages of development? 2. How does it compare with general models of expertise? 3. What is the most appropriate way to examine design expertise given the particular nature of design? The study adopted a cognitive psychological approach, drawing on information processing theory (Newell & Simon, 1972; Anderson, 1993; Kosslyn, 1990).

METHOD

The study involved three practising architects with varying lengths of professional experience. The architects were chosen as they represented different levels of experience, and expertise, with the most experienced having won an award in the 12 months prior to the data collection. In addition, each was involved in architectural practice where they worked, to a large extent, on their own, so that solving a design problem as an individual was a normal part of their everyday working practice. Architecture was chosen for the pragmatic reason that it represented an authentic form of design but one where the activity occurs within a constrained timeframe, unlike other possible design professions such as industrial design or related areas such as invention, where the process can occur over extended periods. As a result, most data collection occurred during single sessions of around 20 minutes' duration.

Table 1. Details of architects

Subject	*A1*	*A2*	*A3*
Age	23	29	62
Gender	M	F	M
Architectural design Experience	1 year	7 years	38 years
Level of expertise (Dreyfus & Dreyfus, 1986)	Competent	Proficient	Expert

Each architect was presented with the design brief shown in Figure 1, below. The intention behind the brief was that it would be effortful for both novice and expert designers because it was complex. It also had to be an activity architects considered authentic. The wording of the brief was developed in collaboration with a practising architect who was not otherwise involved in the study and is shown in Figure 1.

The design problem was complex because it contained potentially contradictory requirements. This was done to ensure that all participants would have to engage in an effortful and conscious process of problem solving and not be able to resort to automated processes or tacit knowledge. The potential contradictions were: the requirement to provide privacy while at the same time providing a light and airy atmosphere; the requirement for passive solar energy on a block that faces south in the southern hemisphere; and a block of land that was small and steeply sloping for a client with arthritis, and as a consequence, the inability to use stairs, which would rule out the possibility of having several levels to maximise space or keep costs down. There was also the overarching constraint that the client had a limited budget.

An elderly female client, with limited funds, requires a detached dwelling on a 450m^2 urban Brisbane block. The site measures 15m X 30m with the shortest alignment fronting the street. The site falls away from the street at approximately 30^0, towards the south and is free of established trees. The best views lie to the South, due to the elevated nature of the site. The client suffers from an arthritic condition and has great difficulty negotiating stairs. She values her privacy but would like the house to have a light and airy atmosphere. She also wishes to take best advantage of natural light, breezes and passive solar energy. She is open to suggestions on the general form and character of the house, and despite her age, could not be considered conservative.

Figure 1. The design problem

Collecting the Data

Data were collected using a modified form of protocol analysis (Ericsson & Simon, 1993). Each participant was presented with the design brief and asked to verbalise all and any thoughts that came into their mind while they solved the problem. They were also asked to solve the problem in the normal way they would solve it in professional practice. Using standard protocol analysis processes, if participants stopped verbalising for more than 10 seconds they were prompted with "What are you thinking now?" Participants were video- and audio-recorded. The video-recording was used to capture the development of the visual aspect of the developing design.

Preparation of Data for Analysis

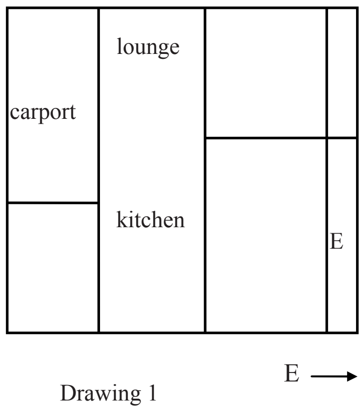
The data source consisted of a video-tape recording of the problem-solving activity of each subject that included a continuous recording of sketching activity and all verbalisations for each of the subjects. The verbal record of problem solving was transcribed and segmented on the basis of achieving the smallest unit of meaning that constituted an instance of a general process, which often meant segmenting at the level of clauses (Ericsson & Simon, 1993). After segmentation, the verbal and visual protocols were placed in columns as shown in Figure 2. Each sketch corresponded to the section of verbal protocol that was produced while the sketch was being generated. That means the participant in Figure 2 started sketching as they started speaking the phrase in line 028 and stopped at the end of line 049.9.

Analysis of the Data

Because participants were engaged in a problem-solving task, the expectation was that they would generate procedural knowledge data. Thus, the verbal data were analysed to establish, initially, the cognitive procedures employed in solving the

027 now taking best advantage of the site ......
028 um, just looking at it as a block diagram

029 I'd have most living spaces and bedrooms on the northern side, so
030 I'll just indicate that's north for now
031 um ... now with the best views …
032 falls away from the street towards the south
033 the best views towards the south
034 difficult, difficult, difficult …
035 I'll probably still keep the bedrooms on the northern side
036 but make it a very linear plan
037 so we take advantage of the views
038 as well as the northern aspect, um
039 which will also help with cross
ventilation
040 so if we could have the carport at
one end
041 and then have the lounge and
kitchen, um
042 I need to know a bit more about
the … client
043 but anyway
044 and then maybe we will spread
045 the ah bedrooms out along one edge
046 there's the bathrooms up…
047 bathrooms and en-suite occupy ... um ....
048 possibly the eastern end of the building
049 so that's east
050 ok, so … let's see



Drawing 1

Figure 2. Illustration of initial representation of problem-solving data

problem. The purpose of this analysis was to examine differences across architects as a function of experience to see how architectural expertise compared with expertise in general. For example, did the expert architect engage in extensive analysis of the problem before attempting to solve it? If so, the data would show significant numbers of exploratory text phrases in the early stage of problem solving.

The purpose of the analysis of the visual data was to identify both the characteristics of the images used in solving the problem, and the function they served in the problem-solving process. In addition, and as with the verbal data, differences across problem solvers of different degrees of expertise were also examined. The following section presents the framework used for coding the verbal protocols that allowed conclusions to be drawn, based on the model of problem solving presented above.

Coding the Verbal Protocols for Cognitive Procedures

Each segment of the verbal protocols of problem-solving activity was coded in terms of cognitive procedures into one of three categories of procedures. The categories were generation, exploration, and executive control. Generation refers to the procedures of retrieval, synthesis, and transformation of knowledge, or, more simply, generating ideas. These procedures have been identified by Finke (1989), Larkin and Simon (1987), and Weber, Moder, and Solie (1990). Exploratory procedures include exploring constraints and exploring attributes. These procedures have been identified by Finke, Ward, and Smith (1992), Gross and Fleisher (1984), and Simon (1973), while executive control includes goal setting, strategy formulation, goal switching, monitoring, and evaluation. Executive control procedures are also referred to as procedures for deciding when to do what. Executive control procedures have been identified by a variety of researchers, including Anderson (1993), Scandura (1981), Chan (1990), Gott (1989), and Perkins (1990).

After coding for cognitive procedures, each protocol was divided into ten equal time segments (tentiles), to allow comparison between subjects at similar stages of the design activity. This made it possible to analyse design activity at any stage of the problem-solving process. For example, experts, in general, spend more time in the initial stages of problem solving analysing the problem before attempting to solve it (Lajoie, 2003). Each tentile was scored in terms of the number of procedures in each category present within each tentile. Figure 3 contains a sample section of verbal protocols from the competent architect.

163	um, she would want a fair bit of space with the laundry	[EC]
164	especially as she may have to use a wheelchair	[EX]
165	one, two, three …	[EC]
166	the bedroom can come back	[GE]
167	it may protrude back again, into the line of the garage	[GE]
168	and can get a window here to the north	[GE]
169	Which will give us some sun in winter	[EX]

Figure 3. Section of verbal data coded for procedures

After coding and separating into tentiles, the data were converted to scatterplots as shown in Figures 4 to 6.

Analysis of Verbal Data

The verbal data provided a useful basis for analysis, particularly when segmented and displayed as scatterplots. Examining the initial plots for all three, important differences appear. The least experienced architect (A1) engaged in rapid generation of solution moves, but quickly slowed down by the fourth tentile where generative procedures were overtaken by exploratory and executive control

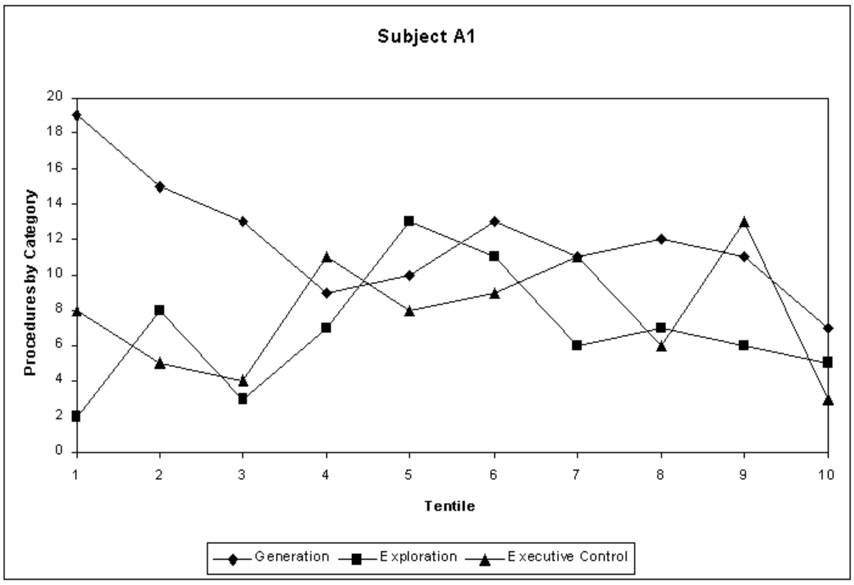


Figure 4. Graph of tentiles for cognitive procedures for the competent architect

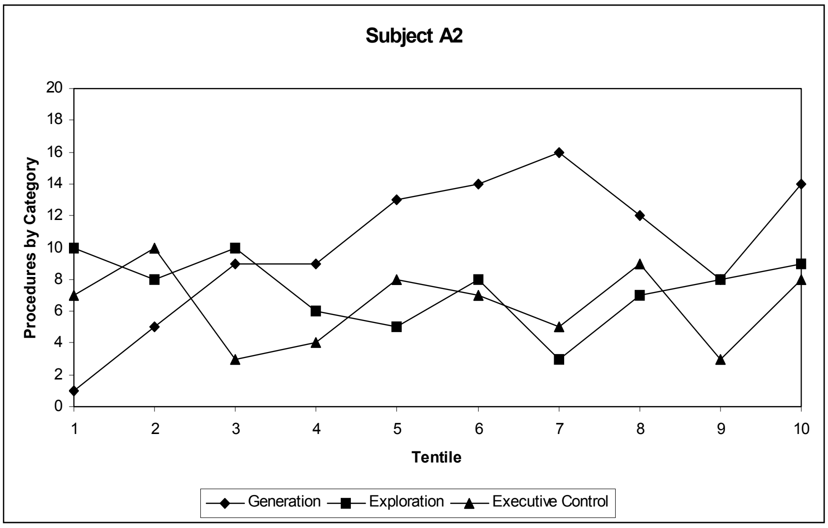


Figure 5. Graph of tentiles for cognitive procedures for the proficient architect

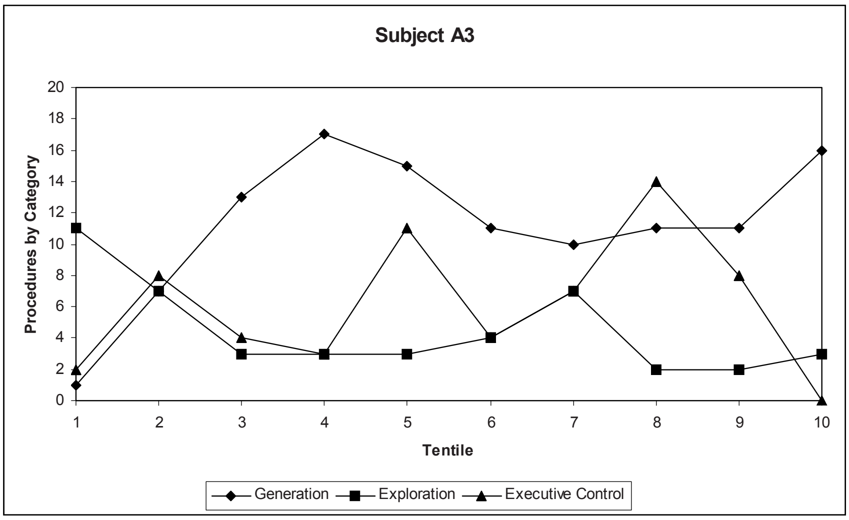


Figure 6. Graph of tentiles for cognitive procedures for the expert architect.

procedures. A1 got into trouble early on and had to spend much subsequent time exploring the problem, trying out ideas, and making decisions. A1 did not produce a solution with which he was happy until tentile 8. Much of A1's activity was consistent with novice-like behaviour in other domains. That is, there was only superficial exploration of the problem before attempting to solve it and much trial and error during the activity, with complexity being discovered as problem solving proceeded. A1 also took the longest to generate a solution.

The behaviour of the proficient architect (A2) indicated a person with more experience. A2 engaged in more exploration of the problem at the beginning, guided by significant executive control procedures. This continued throughout the activity as generative procedures increased to a maximum at tentile 7, at which point A2 had largely completed her solution. Thus, the analysis of A2's cognitive procedures suggests she is more expert that the competent architect (A1) in that she engages in more initial exploration (but less than the expert) before engaging in confident generation of a solution, which occurs sooner in the activity than for A1. Solution generation is largely forward moving, with little of A1's trial and error process.

The expert (A3) displayed a number of expert-like behaviours. A3 engaged in substantial initial exploration of the problem. Much of the exploration was concerned with establishing what aspects of the problem could be solved by his existing architectural knowledge or schemas, and which parts were more complex and required him to generate new ideas. This was followed by confident generation of a solution which appeared by tentile 4. The expert then used the rest of the time to add minor details.

The transition to expertise displayed in the activity of the three architects can be seen in terms of three important features of the analysis of cognitive procedures. The first is the extent of initial exploratory activity, which increased as a function of experience. The second was the manner by which complexity was identified, and the third was the speed of generation of a solution with a consistent speed-up with increasing expertise. The verbal data thus suggest that expertise and the transition to expertise in design has features that appear in studies of expertise in a variety of domains.

Analysis of Visual Data

One aim of the research reported here was to explore how design activity is represented and how visual and verbal data might be used to provide a fuller and more accurate account of design activity and of the transition to expertise than would be the case using verbal data alone. The preceding analysis provided findings from the verbal data. The following section provides an analysis of the visual data generated by the three architects.

In analysing the visual data, a grounded theory approach (Cresswell, 2012) was used. Grounded theory makes no assumptions nor proposes any hypotheses about what will be found in data. Given the scarcity of studies where visual data were the subject of analysis, it was important, first, to identify what might be relevant features of the visual data and, second, to see if there were systematic differences across visual data characteristics or visual data use as a function of level of expertise. This analysis provided seven features of visual data that appeared to be important to any analysis. These were: number of sketches generated; number of sketching episodes; number of sketch types; number of image types; holistic image generation; and time spent sketching. These are summarised in Table 2.

Table 2. Differences in imagery usage

Architects	*Competent*	*Proficient*	*Expert*
Number of sketches	9	5	2
Number of sketch episodes	11	8	5
Number of sketch types	6	3	2
Number of image types	4	2	2
Holistic sketch generated by	mid tentile 9	end tentile 6	Mid-tentile 5
Number of abstract symbols	34	5	3
Time spent sketching as a percentage of total time problem solving	88	75	69

The first important difference across architects was in the number of sketches generated, with a clear progression from nine sketches for A1, five sketches for A2 and two sketches for A3. In reality A3 only generated one main sketch of the solution with one thumb-nail sketch to explore a small detail. The data for number of sketches was interpreted as consistent with features of the transition to expertise.

Sketches were interpreted as expressions of architectural knowledge that became more detailed and integrated as expertise developed.

The second interesting difference across architects was a feature that was labelled sketch episode. It was necessary to create this category because number of sketches did not cover one aspect of the activity which was the switching back and forth between different sketches, which occurred most with A1 and was almost absent with A3. Switching between sketches was interpreted as indicating an architect who did not have detailed architectural knowledge and needed to break the problem down into more manageable parts.

Number of sketch types was included because the least experienced architect (A1) produced the largest number of sketch types and these appeared to be the application of representations learned during university study (A1 was in his first year of professional practice). Each sketch type was used to explore or generate one aspect of the design solution. The proficient architect (A2) used fewer sketch types and the expert (A3) used only one type. However, the expert's sketch was complex and suggested a higher level of integration of architectural knowledge.

Number of image types was a feature of the visual data that was complex to identify but was an observable difference across the architects. To identify differences in imagery types, it was necessary to examine visual and verbal data concurrently as sketches on their own provide evidence of imagery usage but do not necessarily indicate their functional properties, for example, if architects were using sketches to simulate the way a client would move through a house. Analysis of image types indicated that A1 used static, abstract, zoomed (as in zooming in with a camera), and rotated images, while A2 used static and rotated images and A3 used static and dynamic images (images that suggested movement). There was a progression in image type usage with less experience associated with more image type usage, and more experience associated with usage of fewer image types. As with sketch types, usage of greater numbers of image types by A1 is interpreted as indicating both a usage of formally learnt processes and the inability to generate more complex, integrated images.

Another difference across architects was the point in the activity when all significant elements of the design were visible. This point was never the end of the activity but any activity after this point involved completing detail that did not change the basic design. A1 generated what I describe as an holistic design by tentile 8, A2 by tentile 7, and A3 by tentile 4. This result is consistent with existing research that found that experts produce solutions faster than less-experienced practitioners (Lajoie, 2003). It is interesting to note that cross-referencing visual data with the tentiles of cognitive procedures indicates that the point at which each architect generated their holistic sketch was also the tentile with the most generative activity.

Use of abstract symbols was another observable difference across the visual data. These included names, notes, and direction arrows and are interpreted as both aids to memory and cues to the progress of the activity. A1 used 34, A2 used 5, and A3 used 3. The progression in terms of decreasing use also suggests architectural expertise involves more complex and integrated visual data with less need for memory aids (Lajoie, 2003).

The final feature of the visual data was time spent sketching, with A1 spending the most time and A3 the least, with A2 in between. This was an interesting observation as sketching activity was largely associated with generative procedures. This means A1 spent almost all his time (88%) generating, leaving little time for exploration or executive control procedures, that is, engaging in deep thinking about the problem prior to generating a solution. In that sense, A3's time spent sketching was consistent with expertise, with A3 having spent the least time sketching and consequently the most time exploring the problem. The verbal data confirms this interpretation of the visual data.

Combining the Analyses of Verbal and Visual Data

Combining the analyses of verbal and visual data achieved a number of goals. It allowed triangulation of data that confirmed that many features of expertise in general were present in design expertise. As noted earlier, these were time spent exploring the problem, the manner by which complexity was identified, and the speed of production of solutions.

Analysis of the combined data also suggested the problem-solving model proposed by Middleton (2002) was useful in representing ill-structured problems in domains such as design. The data suggested that all architects found the task complex and one where each had to establish their own starting points, their own solution to the problem (there were significant differences between the designs), and each engaged in a process of identifying solution elements from existing knowledge and creating new elements, as predicted by the model.

The study confirmed the central role of visual images in designing and the importance of using visual data in analysing design thinking. With up to 88% of time spent sketching, visual data were central in allowing confident interpretation of the designing activity.

Finally, when undertaking research it is often the case that most results are predicted at the outset, hence the use of hypotheses. However, it is also often the case that some of the most interesting findings are those that were not expected, and this was the case with this study.

During the analysis of the verbal data it was sometimes the case that deciding on the category of cognitive procedure was difficult. In these instances, it was helpful to view the combined data via the video-recording. This was both illuminating and occasionally alarming. For example, on one occasion both A1 and A2 produced identical verbalisations, for example, "we have one bedroom, a second bedroom and a third." However, when one viewed the video it was clear that A1 was sketching the rooms, and thus engaging in a generative activity, while A3 was simply pointing to each room in turn and thus engaging in the executive control activity of monitoring.

This highlights the strength of using combined data but also indicates a potential weakness of some forms of verbal data. This includes verbal data where research participants are verbalising the performing of a task and there is not the opportunity to clarify meaning, as is the case with an interview. People use identical or similar words to indicate various meanings and caution needs to be exercised in analysis unless there are other data that can be used to either support or clarify meaning as was the case in this study.

CONCLUSIONS

The study reported here suggests that design expertise has many features that are found in expertise in general, and the transition to expertise in design is also similar to the transition in other domains. The study did conclude that to produce findings about design thinking and activity confidently it was important to use data that represented the way design activity operated. This involved using both verbalisations and visual imagery data to represent design thinking and action.

The study did support the utility of the problem space model proposed by Middleton (2002) as a way to characterise the particular properties of design problems. This was evident in the way the three architects navigated the search space and in the different ways they identified the problem and the kinds of solutions they proposed. These differences were in addition to the more general differences that were a result of their levels of expertise.

The study has implications for the way we research the learning process in technology education or design and technology education subjects. As with professional design, students involved in designing engage in activities that are both verbally and visually mediated and we can gain meaningful insights into student design processes only if we use methods that acknowledge that reality.

It does need to be said that while the study reported here involved the collection and analysis of rich and detailed data, it did involve only three participants. As such, caution needs to be exercised in making generalisations. However, the study does provide the basis for further research into the thinking processes of both experts and practitioners developing expertise in particular domains. These include domains where the solving of ill-defined problems occurs and creative thinking is required.

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