Comparing graphic actions between remote and proximal design teams

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This paper outlines the conduct and findings of a research project which compared the sketching activity and sketched output of pairs of design students collaborating face-to-face with other pairs linked by computer mediated tools. The paper proposes that attention to the nature and dispersion of 'graphic acts' can lead to a better understanding of the exploitation of sketching between remotely located design participants. Sketch Graphic Acts are used to illuminate the phenomenon of shared sketches and the importance of 'thumbnail' sketches—which were commonly exploited in laboratory studies of face-to-face collaborative working but which were significantly impoverished in studies of computer mediated, remote collaborative working.

Keywords: drawing, collaborative design, computer supported design, industrial design

Sketching, as a particular subset of drawing, has previously been shown to support communication in much the same way that other, more formalised, drawing conventions can do (see, for example, Garner and Evans[1]). However, the relationship between sketching activity and the cognitive processes involved in creative and developmental design by individuals and teams is still the subject of debate. The significance of conjecture in design activity has been eloquently summed up by Bruce Archer in his Presidential address to the Design Research Society in 1998[2] but, before this, Goel[3] was presenting sketches as ambiguous conjecture which function to hold emerging concepts open to continuous development. Fish[4] dissects this notion further to reveal how external, constructed models in the form of sketches make unique contributions to cognitive transformational processes central to creativity and the emergence of ideas. This relationship between sketching and emergence has occupied many recent researchers (e.g. Tapia[5]). More recently, Casakin and Goldschmidt[6] suggest an important relationship between the ability to exploit visual analogies

1 Garner, S and Evans, M 'Communication in design', in **J Williams and A Williams** (eds) *Technology Education for Teachers* Macmillan Education, Australia (1997) pp 111–135

2 Archer, L B 'Design, innovation and agility' *Design Studies* Vol 20 No 6 (1999) 565–571

3 Goel, V *Sketches of Thought*, MIT Press, Cambridge, MA (1995)

4 Fish, J *How Sketches Work: A Cognitive Theory for Improved System Design* (PhD thesis) Loughborough University, UK (1996)

5 Tapia, M A 'Emergence', part of the workshop into interactive systems for supporting the emergence of concepts and ideas and published as part of *CHI 97*, 22–27 March, University of Atlanta, GA, USA (1997)

6 Casakin, H and Goldschmidt, G 'Expertise and the use of visual analogy: Implications for design education', *Design Studies* Vol 20 No 2 (1999) 153–175

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and successful design problem solving. Like Fish, they also propose that the type of visual analogies represented via sketch drawing assist the structuring of design problems through transformation—a process of interrogation and reformatting of information. Design progression, it would seem, requires an integrated strategy for creatively interpreting and transforming the partly-known problem, and for creatively responding via the generation and expression of ideas. The widespread use of sketching in design activity would seem to suggest that it offered appropriate support to both the defining and resolving of design problems. This paper examines these notions in the context of computer mediated collaborative designing.

In 1998 the author returned to a collection of research data generated in earlier studies of computer supported collaborative working (CSCW). These studies had been undertaken as the Rococo project at Loughborough University between 1988 and 1992 and this project is summarised in the next section. Sceptics might be critical of the use of 'old' data for new research studies. After all, there have been significant developments in the technology; computing and telecommunication costs have been vastly reduced allowing exploitation of CSCW in many fields of work and research studies in the intervening years have added considerably to our knowledge regarding user requirements and the application of CSCW tools. The original data had allowed the original research team to examine a variety of issues concerning verbal and non-verbal communication but it seemed that embedded within the data was further valuable information regarding the use of drawing—and more particularly, freehand sketching—within computer mediated collaborative designing. Importantly, there was not, and still is not, a vast body of research to call upon. The support of sketching between remote participants within CSCW has received less attention than, say, verbal communication or more formal types of non-verbal communication. The next section provides an outline of the original study which generated the data revisited in what came to be known as the Analysis of Graphic Acts (AGA) project.

1 The foundation of the research—Rococo

The Rococo project was a Research Council funded project in the field of CSCW. The title derived from the project's field of study, that is, remote communication and co-operation—and it was led by Steve Scrivener. The project's key aim was to specify the communication requirements of remote participants engaged in CSCW and it proposed to do this via studies of pairs of undergraduate student designers. It was a timely proposal since other CSCW studies were emerging in other centres around the world (see, for example, Bly[7]; Tang and Leifer[8]). The research proposal had highlighted the need to understand and articulate requirements in communi-

7 **Bly, S A** 'The use of drawing surfaces in different collaborative settings' in *Proceedings of the Second Conference on Computer Supported Cooperative Work*, University of Portland, OR, USA (1988) pp 250–256

8 **Tang, J C and Leifer, L J** 'A framework for understanding the workspace activity of design teams' in *Proceedings of the Second Conference on Computer Supported Cooperative Work*, University of Portland, OR, USA (1988) pp 244–249

cation-rich, design team working if computer based systems for the support of collaborative design were to be improved. The Rococo project defined a study, in two conditions or phases. One phase studied traditional face-to-face working while a second phase studied participants who were located remotely from each other but linked by computer based communication technology. The Rococo project used industrial design as the research context and used pairs of student designers as subjects. Phase One of the project was concerned with proximal working. The laboratory was set up to provide a working environment which was acceptable and, in many ways, familiar to those with experience of creative professions such as design. Pairs of second year students shared a large flat-topped table and also shared a range of writing and drawing equipment including pens, pencils, markers and a large (A1 size) pad of plain paper as they worked on an industrial design brief provided by the researchers. They could talk, gesture and draw with the minimum intrusion of technology and in this way Phase One provided benchmark findings for comparison with the second phase (Figure 1). There were six studies and each lasted 1 h. Two video cameras recorded the actions, one focused on the drawing surface and the other presented a wider picture of the scene. An audio recording was also made. Participants were briefed on the task. They were not permitted to leave the studio, nor were they permitted to undertake any research. They were not provided with any materials with which to construct three-dimensional models. Further data was captured in a post-study questionnaire completed by all participants.

In the second condition, Phase Two, each study consisted once again of a pair of student industrial designers who this time were located in separate rooms. Subjects were provided with links to each other via headset tele-

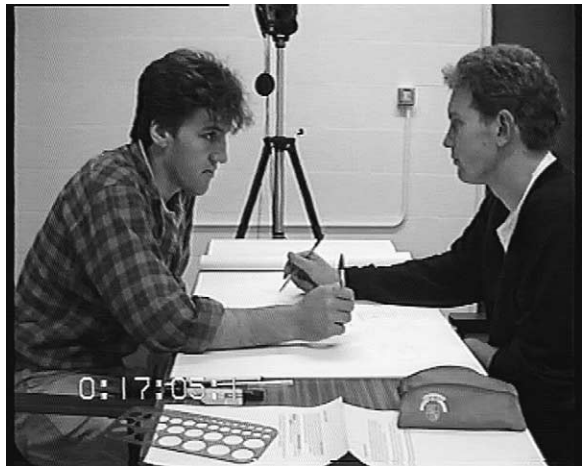

Figure 1 A pair of subjects involved in a Rococo Phase One (proximal) study

phones, video link and a computer-mediated drawing surface. The video link appeared on a second monitor screen to the side of the drawing screen. This provided an upper body image of the partner and allowed an impression of eye contact between participants via an arrangement of one-way mirrors (visible in Figure 2). It also enabled participants to see the gestures of their partner. While the A3-size graphics tablets and pens for sketching were commercially available the project chose to develop its own software (by Shaun Clark). This enabled both participants to sketch simultaneously in a shared window on the main monitor screen plus a full record of all graphic activity was retained. Each pair was again provided with an industrial design brief for the 1-h task.

While there were six studies in Phase One, Phase Two was much larger because it sought to examine the nature of communication and collabor-

Figure 2 A pair of subjects involved in a Rococo Phase Two (remote) study

ation achieved with different permutations of communication tools. That is, five studies were undertaken with all communication tools switched on ('all on'); five with no audio link ('video only'); five with no video link ('speech only') and five with no audio or video link ('drawing surface only'). In this way considerable data were generated regarding the relative use of channels of verbal and non-verbal communication during team design work. Only the six Phase One studies and the five 'all on' studies of Phase Two were included in the AGA project. The video tapes have proved the most useful to revisit for the purposes of the subsequent AGA project—more so than the actual drawing output. The drawing pages from Phase One exist as hard copy but those from Phase Two were retained as computer files. Elapsed time within the 1 h studies was used as a common reference point for the various analyses.

It was anticipated that findings concerning the use of sketching in proximal and remote collaboration would be weaker without some measure of the relative quality of the design work produced by each pairing. Therefore as part of the revisiting of the data the design proposal which emerged from each pairing was evaluated by the author to provide a score for design quality. This identified six aspects for assessment and required that each be graded from poor to excellent on a five-point scale. Briefly, the six aspects were communication, finish, relevance, plausibility, inventiveness and appropriateness. Each grading was converted to a numerical value and the sum of all six values produced a single quality rating as a percentage. This quality assessment procedure was repeated in a second blind assessment by another experienced design tutor. Since it produced no significant difference in quality assessment ratings the authors ratings were used.

2 *The analysis of graphic acts (AGA) project*

For the purpose of the AGA project a drawing (noun) refers to a discrete and identifiable graphic output which might have pictorial (sketch) or written elements or both. The act of drawing (verb) here refers to making pictorial images (sketching) and/or writing. The paper-based records of drawing activity are referred to as pages or drawing sheets. Together with the video and audio records they provide the data for analysis. Having given every drawing from both conditions its own identifying number it was possible, by using the video recordings, to chart the history and development of each drawing by documenting the individual contributions. These contributions have been termed Graphic Acts by the author and are based on 'Drawing Acts' which were defined by the Rococo project (see Scrivener and Palmen[9]).

Some drawings consisted of only one Graphic Act. Others consisted of

9 Scrivener, S A R and Palmen, H 'An analysis of face-to-face drawing activity' in **J S Smith** (ed.) *Proceedings of 4th National Conference on Design and Technology Education (DATER 91)*, Loughborough University, UK (1991) pp 200–214

several Graphic Acts over a period of time—often by both partners. Defining a Graphic Act was not straightforward. Indeed, one of the important findings of earlier research by the author (Garner[10]) was the complexity of drawing behaviour, the variety of exploitation and the difficulty of categorisation. If one watches someone sketching it is clear that the activity is made up from a sequence of active and reflective processes involving mark-making and evaluation. The difficulty with defining Graphic Acts concerned the level of detail required. If every occurrence of mark-making was recorded then one achieves a very fine level of detail but at the expense of a very time-consuming process. If, on the other hand, one recorded long sequences of activity as a single Graphic Act then one achieves a low level of detail, perhaps saving time and effort, but potentially losing much of the richness of drawing. For this analysis, Graphic Acts were defined as 'continuous sketching or writing activity where pauses, interruptions etc., are less than one second in duration'. This definition allowed a subject to take their pen or pencil off the paper or tablet and then continue as part of the same train of thought. Any hesitation, pause or interrupt causing a break in graphic activity for more than 1 s was deemed to mark the end of that particular Graphic Act and a new one began when the individual next started drawing. Scrivener and Palmen[9] exploited 1-s interrupts in their analysis of 'Drawing Acts' and this seemed to provide an appropriate level of detail. The AGA data collection consisted of watching the video records of each proximal and remote study several times to document the Graphic Acts of one of the subjects and then a second time to document the Graphic Acts of their partner. Of particular interest in this research was the use of 'Sketch Graphic Acts' (SGAs): a particular type of graphic act leading to pictorial rather than numerical or textual content.

3 *Introduction to the statistical comparisons*

Having completed the data collection a comparison of the two phases was undertaken. Any test for significant difference between the findings of Phase One and Phase Two had to acknowledge the particular characteristics of this research—not least that it used very small samples. While the subjects were all drawn from the same student group the two phases used independent samples—that is, participants were not matched or paired. Also, some of the data consisted of 'scores' which were ordinal rather than nominal. Since a number of parametric assumptions were violated then nonparametric statistical tests offered the most relevant means for analysing the data and the Mann–Whitney test was adopted.

Table 1 presents a summary of the data and the results of the Mann–Whitney tests performed using the computer based statistical programme SPSS (V.6). For each comparison (for example, 'number of sketch drawings

10 **Garner, S** 'The undervalued role of drawing in design', in **D Thistlewood** (ed.) *Drawing Research and Development*, Longmans, London (1992) pp 98–109

Table 1 Comparison of Phase One (proximal pairings) with Phase Two (computer supported remote pairings)

	Phase One		*Phase Two*		
Outputs	*Mean*	*SD*	*Mean*	*SD*	*M–W test*
Design quality rating	66.6	12.1	55	8.3	
Time engaged in graphic activity (min/s)	35.21	616 s	53.17	494 s	*
Number of drawings produced	67	15.6	47	3.7	**
Number of sketch drawings produced	54	10.3	45	3.6	
Number of shared sketch drawings produced	12.2	2.8	16	3.2	
Number of SGAs produced (per pairing)	173	31.7	201	26.8	
Number of SGAs per sketch	3.29	0.5	4.52	0.6	**
Percentage of SGAs in three most visited sketches per subject	32%		29%		
Number of SGAs committed to shared sketches	80	25	122	29.2	
SGAs committed to sketches as percentage of SGA output	46%	12	61%	14.4	
Sketches comprising three or less SGAs	40	9.8	23	4.8	**
Sketches comprising three or less SGAs as percentage of total sketch production for each pairing	74%	5.6	51%	10.8	**

produced') the overall mean and standard deviation (SD) is shown for both Phase One and Phase Two. The final column summarises the level of significance as:

*significant (significance at the 5% level—$p<0.05$); and
**highly significant (significance at the 1% level—$p<0.01$).

Blank spaces in the final column indicate that no significant difference between the phases was found.

4 *Discussion of Table 1—significant and highly significant differences between phases*

4.1 *Time engaged in graphic activity*

This row presents the means of the combined time of subject A and subject B being engaged in graphic activity. It was a crude measure of the amount

of graphic activity being undertaken by each pairing in each condition. The Mann–Whitney test resulted in an indication of 'significance'. A two-tailed test was relevant here since it was not predicted whether the time engaged in graphic activity would go up or down between conditions.

The mean time for each condition was surprisingly different—35 min 21 s in Phase One and 53 min 17 s in Phase Two (note that these means derive from combined timings for both partners and therefore have a maximum of 120 min). Phase Two participants spent 51% more time making graphic acts than their Phase One counterparts. For some reason remote partners needed to make greater use of their stylus than would be the case if they were proximal and using traditional pen and paper. It might be that drawing was being used to maintain a common focus of attention on the monitor screens, that is, used as a 'pointing' or 'attention-getting' device. In Phase One the video records revealed substantial periods of non-drawing activity as partners talked or, in some cases, remained in silent and private thought and this partly accounted for the lower mean time. When drawing was resumed by one partner in proximal collaboration this was immediately obvious to the other via the physical act it required. In the remote condition such body and arm movements were much less apparent and the more frequent use of drawing may have been an attempt to compensate for this. There was potentially a greater sense of isolation in the remote setting and it would be understandable if writing and sketching was being used to establish and maintain a constant contact with the remote partner.

4.2 Number of drawings produced

In this row 'drawings' include discrete written or numerical entities such as lists as well as pictorial sketch imagery and the number refers to output per pairing. There was a 30% decrease in overall drawing production when subject pairs worked in the computer supported remote condition (the mean dropped from 67 drawings to 47 drawings). As the direction of change was not anticipated, a two-tailed Mann–Whitney test was appropriate and it revealed a highly significant ($p<0.01$) difference. The reduction in output of drawings in Phase Two might have been to do with subjects lack of familiarity with computer based tools—for example the use of stylus and graphics tablet as input devices. Alternatively it might have been related to differences in available drawing space—the proximal condition used A1 size paper while the remote condition limited participants to an 18″ monitor (both conditions, however, provided access to as many 'pages' as subjects required). It might also indicate a preference to work-up existing sketches, lists, etc, rather than instigate new ones. The production of less drawings is not necessarily important. It may be that subjects were working more

efficiently, especially when one considers that no significant difference was found between the design quality assessments of the two phases.

4.3 Number of SGAs per sketch

While no significant difference was found between the two conditions in number of sketch drawings produced per pairing and number of SGAs produced per pairing, this comparison provided a revealing finding concerning the relationship between the two. The comparison reveals there were 37% more SGAs per sketch in Phase Two (mean 3.29, SD 0.5 in Phase One and mean 4.52, SD 0.6 in Phase Two). The Mann–Whitney test (two-tailed) revealed a highly significant difference between the two conditions ($p<0.01$). However, the mean of SGAs per sketch can be a potentially misleading statistic. SGAs were not spread evenly over all sketches as the rows titled 'percentage of SGAs in the 3 most visited sketches for each subject' and 'sketches comprising 3 or less SGAs as a percentage of total sketch production for each pairing' reveal. Nevertheless, given this highly significant difference between the conditions one may be confident in identifying a change in sketching when subjects were placed in the computer mediated setting. They spent more time engaged in graphic activity; they produced fewer drawings overall but used a greater proportion of shared sketches and each sketch contained a greater number of SGAs.

4.4 Sketches comprising three or less SGAs

The video analysis allowed a clear and unambiguous counting of sketches which received three visits or less (by either partner or both). The Mann–Whitney test found a highly significant difference between the two conditions ($p<0.01$) in a two-tailed test. The difference between the means reveals a Phase Two decrease of 42% in the production of sketches with three or less SGAs (Phase One 40%, SD 9.8; Phase Two 23%, SD 4.8). This finding may be largely distorted by differences in volume of sketch production and therefore an additional comparison was necessary and is shown in the final row in Table 1.

4.5 Sketches comprising three or less SGAs expressed as a percentage of total sketch production for each pairing

This row takes into account the differing production of sketches between the two conditions and it reveals a real decline in Phase Two of 31% of those sketches which contain three or less SGAs (Phase One 74%, SD 5.6; Phase Two 51%, SD 10.8). The Mann–Whitney test indicates a highly significant difference ($p=0.011$). These sketches which contain three or less SGAs (which may be shared or not shared) may be viewed as 'thumbnail'

sketches. They will be familiar to most who have been engaged in creative graphic work. They are characterised as fast, transitory sketches which may be used to communicate particular phenomenon (such as the size of a hole or the outline form of an artefact) or as a private, developmental device used in conjunction with internalised creative processes. The findings reveal that these thumbnail sketches were much less used in the remote condition but the effect was less easy to identify given the lack of significance in the difference in design quality ratings.

5 *Summary of findings and observations from the AGA project*

- Remote participants spent 51% more time making graphic acts than their proximal counterparts. This was statistically significant. Partly this can be explained by the existence of extended periods of non-drawing time in the proximal studies.
- No significance was found in the differences in design quality assessment between the two conditions.
- There was a 30% decrease in overall drawing production when subject pairs worked remotely. This might be associated with a lack of familiarity with the computer tools or inherent restrictions such as screen (page) size.
- In spite of producing a 17% lower mean number of sketches in the remote condition, the mean number of shared sketches was 31% higher. While not statistically significant this might suggest that remote pairs found it preferable to work-up their own sketches, and those of their partner, in their collaborative designing rather than begin new sketches.
- No significant difference was found in the production of SGAs.
- There were 37% more SGAs per sketch in the remote condition and, statistically, this was highly significant. Again, remote pairs preferred to work-up existing sketches rather than create new ones.
- 52% more SGAs were committed to shared sketches in the remote condition.
- The remote condition presented a 'highly significant' 42% decrease in the production of sketches with three or less SGAs (characterised as 'thumbnail' sketches). When this was corrected for variation in overall sketch output there was still a 31% decrease in the output of this type of sketch.

6 *Conclusions and discussion*

Pictorial representations, constructed during designing and taking the form of sketches, are important to designing because they impose both order and tangibility on the one hand, while on the other hand their ambiguity

stimulates reinterpretation. It is not just the potential speed of sketch generation which assists cognitive processing. The very lack of clarity inherent in freehand drawing may be an important catalyst in creative transformation of information. The AGA project reveals that sketching within computer mediated designing may be significantly impoverished in certain key respects. Participating pairs who were remote but linked by computer tools spent more time than their proximal counterparts engaged in sketching activity; they produced fewer sketches overall but used a greater proportion of shared sketches and each sketch contained a greater number of SGAs. There was a 31% decrease, in real terms, in the production of what has been termed 'thumbnail' sketches. If these fleeting and potentially ambiguous sketches have anything to do with the support of cognitive, creative, transformational processes then there may be something here which requires further investigation. The aim for researchers in this field, as Suwa and Tversky[11] point out, must be to enable the development of computer based design tools which 'enrich perception' and which most likely will involve the support of some kind of sketching capability. The fluctuations in sketch graphic activity seen in the AGA project may not in itself be an issue given that no significant difference was found in the comparison of output quality. However, the findings reveal that computer supported pairings are revisiting more drawings and creating less new drawings—particularly those thumbnail sketches which contain three or less SGAs—than their proximal counterparts and this is a potential cause for concern. One may speculate on the reasons why remote participants preferred to work up existing drawings. Perhaps lack of familiarity with the input devices meant that over-drawing was preferable; perhaps it was easier to bring a remote partners attention to an existing rather than a new image. Perhaps, as Maher et al.[12] suggest, shared sketches acquire significant levels of shared understanding during collaborative design. If this is the case, communication of intent between participants would be easier using existing sketches than creating new sketches which potentially contain little or no shared understanding.

This research has become all the more important with the proliferation of low-cost telecommunications, new input devices and CAD software which enable computer supported collaborative designing. However, as researchers such as McGown et al.[13] point out, one needs to examine carefully the qualities of sketching directly into the computer before dismissing traditional paper based techniques or hybrid approaches such as using facsimile machines or scanning paper images. There is still much support for the speed, value and efficiency of paper based sketching (see, for example, Tovey[14]) or what Stappers and Hennessy[15] refer to as the quality of PAD—paper aided design!

11 **Suwa, M and Tversky, B** 'What do architects and students perceive in their design sketches? A protocol analysis' *Design Studies* Vol 18 No 4 (1997) 385–403

12 **Maher, L M, Simoff, S J and Cicognani, A** *Understanding Virtual Design Studios*, Springer-Verlag, London (2000)

13 **McGown, A, Green, G and Rodgers, P A** 'Visible ideas: Information patterns of conceptual sketch activity' *Design Studies* Vol 19 No 4 (1998) 431–453

14 **Tovey, M** 'Styling and design: intuition and analysis in industrial design' *Design Studies* Vol 18 No 1 (1997) 5–31

15 **Stappers, P J and Hennessy, J M** 'Computer-supported tools for the conceptualisation phase' in **G Goldschmidt and W Porter** (eds) *Proceedings of the 4th International Design Thinking Research Symposium on Design Representation*, MIT, Boston, MA, USA (1999) pp 177–187

Product design appears to be a suitable field for an examination of the sketching activity of participants but this is not to say all fields are equally appropriate. Latch Craig and Zimring[16], for example, highlight the unusual nature of architectural design which, they propose, displays more complex sketch imagery (and presumably less of the thumbnail sketch output) than might be the case in product design. Other observations contradict this, for example, Cross[17] who identifies a clear use of thumbnail sketches in major architectural projects. Drawing research using design subjects must also question what Yair et al.[18] refer to as 'forms of knowledge'. Their research begs the question how might 'crafts knowledge' (as opposed to design knowledge) inform sketching activity within collaborative design?

The status of research into design sketching has been considerably enhanced in recent years. Purcell and Gero[19] point out that sketching is no longer viewed as a mere 'skill' but as 'an essential part of the process of thinking about a design problem and developing a design solution'. Another influence on status is the demand for, and value (both commercial and intellectual) of, new knowledge about sketching within CSCW. Computer supported design team working is only one of a number of CSCW applications but it is a useful one for research into sketching because of the visual emphasis within design. There are two further issues which emerge from the research discussed above. One concerns the nature of future research into computer supported design team working and the second concerns the implications of such research outside of design. Firstly, new types of sketching research studies will need to be designed. Such research should aim to provide knowledge which will support designers in appropriate ways and this may mean integrating old and new media (such as paper and portable communication devices) and integrating old and new procedures. The value of studies outside of the subject's normal place of work could be questioned, with more research involving designers in their own environments. Secondly, real developments in our understanding of, and support for, sketching will come about when findings from computer supported design team working are integrated into other fields of CSCW. The latest work by the author is examining the use of sketching by hospital staff in order to better support their particular needs in defining and resolving problems, consulting, teaching and communication within CSCW. If sketching is as important to thinking as recent research suggests then there are radical implications for education, employment and leisure which extend way beyond design.

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16 **Latch Craig, D and Zimring, C** 'Supporting collaborative design groups as design communities' *Design Studies* Vol 21 No 2 (2000) 187–204

17 **Cross, N** 'Natural intelligence in design' *Design Studies* Vol 20 No 1 (1999) 25–39

18 **Yair, K, Tomes, A and Press, M** 'Design through making: Crafts knowledge as facilitator to collaborative new product development' *Design Studies* Vol 20 No 6 (1999) 495–515

19 **Purcell, A T and Gero, J S** 'Drawings and the design process' *Design Studies* Vol 19 No 4 (1998) 389–430