Meta-cognition and Design and Technology Education

Abstract

Using a case study approach, this paper explores meta-cognition in a design and technology setting. It reviews briefly the nature and role of meta-cognition in design and technology education and then describes a 'schema' that was conceived originally to analyse, but became a means to promote, meta-cognition in the respondents of a study. The main body of the paper identifies and discusses meta-cognition 'in action' of one respondent from that study. Overall, this paper aspires to explore two questions: how confident are we in identifying meta-cognition in practice (what does meta-cognition look like, sound like, in a design and technology *milieu*?); how can we develop and promote it further in learners?

Dr Roger Elmer

King Alfred's College of Higher Education

RESEARCH

Aims

The aims of this paper are:

1. to review briefly the nature and role of meta-cognition in design and technology education
2. to describe an analytical tool that was used by the respondents of a study (1991-1995) to promote their meta-cognition
3. to identify and discuss meta-cognition 'in action' of one respondent from that study.

In the construction of this I have been mindful of external events. A number of commentators (Kimbell, 2001a; Kimbell, 2001b, Shirley, 2001) have cited the present interest in design and technology by others (e.g. David Hargreaves). Publications have responded to this challenge (Kimbell and Perry, 2001; Barlex and Pitt, 2001; Harrison, 2001) but too frequently there is a need for evidence to support our claims. This research work seeks to contribute to these debates in general and specifically Kimbell and Perry (2001).

The role of meta-cognition in design and technology education

This section commences with a very brief review of the educational aims of design and technology and seeks to trace the emergence of meta-cognition within them. The motives for the inclusion of design and technology as a distinct component in general education in the UK has been, and continues to be, a contested ground. Vocational and citizenship arguments have been propounded, but others would advance an 'intrinsic value' rationale. In sharp distinction to propositional knowledge, 'knowing that', this view would see that at the core of design and technology is procedural 'knowing how'; knowledge which empowers its holders in the realms of practical action. Design and technology is a learning process, capability in which is an appropriate interaction of knowledge, skills and values, and not simply the aggregation of levels of understanding and performance in discrete areas. This argument could be traced through Dewey (1933, 1938), Schon (1985), and Archer's *a third culture* (1979). For adherents of this view the ideas expressed in the 1987 Assessment of Performance Unit (APU) report (Kelly *et al*, 1987), and then expanded and given even greater emphasis in the 1991 report (Kimbell *et al*, 1991: 21) are at the core of the subject's educational aims. Kimbell, Stables and Green (1996), drawing on the research work of the APU and the Understanding Technological Approaches project (on both of which Kimbell and Stables were principal researchers), propose and celebrate the uniqueness of the language employed in design and technology:

> 'the language of technology is indisputably a concrete one – of images, symbols and models. Without this language it is just not possible to conceive of technological solutions.' (*ibid*: 23)

This proposition leads to the central curriculum justification for the study of design and technology. Modelling, the language of design and technology, has the potential to give access to learners' thought processes, in particular how they have gone about the learning task. Concrete modelling (Archer, 1982 and 1992) has the potential to provide an externalisation of a learner's cognitive modelling (*ibid*) and it is through the relative accessibility of this concrete modelling that learners have access to their own 'thinking-in-action'.

> 'Design and technology not only enhances the thinking and decision-making powers of young people, it also enhances their *conscious awareness* of those thought processes[2]. They not only learn to think and make decisions, they also know (and can see) that that is what they are doing.' (Kimbell *et al*, 1996: 31)

> 'Note 2: The term 'meta-cognition' has been applied to this phenomenon.' (*ibid*: 35)

To summarise this position, modelling is at the core of design and technology capability and its external manifestation provides learners and their teachers with 'a concrete lever' that can expose and get a purchase on learners' thought processes. Although these thought processes are ostensibly concerned with designing (making change to the made-world), they are intrinsically manifestations of learning (making change to the learner). If design and technology is cast within this wider sphere, then modelling is not just the

means by which a design is 'pushed forward', but it is a means by which learners, and their teachers, can gain an insight into the processes of their own learning; it is a tool to access meta-cognitive activity.

Elsewhere in the design and technology literature I would suggest that the term has had at best a peripheral status. There are exceptions to this (Lawler, 1997) but in many publications it is not mentioned (e.g. Eggleston, 1996), others cover it in a few sentences (e.g. Hennessy and McCormick, 1994), and in others it is implicit rather than explicit (e.g. Ritchie, 1995).

However, in a very recent, and I believe powerful and eloquent, review of the distinctive contribution which design and technology makes to the school curriculum, Kimbell and Perry (2001: 14) state (my emphasis in bold):

> 'A key part of this process [decision making in a turbulent environment] relies on developing learners' 'meta-cognition', their ability to stand outside themselves and look in at their own designing. [...] **The transfer of learning that results for students from such meta-cognitive grip on their own thinking is enormous. It underpins our claim that through design and technology, students acquire higher order thinking skills.**'

The genesis of this paper was the desire to explore this claim and bring some evidence to the debate concerning design and technology and the development of meta-cognition.

An analytical tool used to promote meta-cognition

Background

The context of the original study was a BA Design and Technology/Certificate course (the BA) at a college of higher education in the United Kingdom. Following two common years the course allowed a choice of pathway leading to a Certificate for secondary school teaching or industrial employment. As its course director I had a particular interest in the BA and this interest prompted an extended study (Elmer, 1996).

A representative sample of eight students (the respondents) was drawn from the 1991 cohort. The predominant fieldwork method was semi-structured, recorded interviews that were conducted in each term of the course. They were transcribed in order to analyse the data and varied in scale between 4,000 to 10,000 words for each respondent in each field location.

Methodological considerations

For this study, with its overarching aim of trying to find out what students do believe and understand rather than what they think they ought to believe, a methodology within the ethnographic tradition appeared the most suitable to minimise the influence of any prescribed view of design and technology. From its genesis as a means of studying, in their natural setting, the networks of moral and material affiliations of small communities in non-industrial societies, ethnography now refers to the detailed study of small groups within any society. It has always been concerned with the minimal manipulation, disturbance or interference by the observer of the setting and its emphasis is on the understanding of the meanings which underlie social action.

I acknowledge that I had a stake in the respondents' responses in the school setting, as their teaching practice supervisor, and in all settings as director of their course and an assessor of their work. This power relationship and the need to bracket my own conceptions were recognised at the outset of the study and they were addressed in a number of ways but particularly by the inclusion in all the earlier fieldwork of a cluster of very open questions (ones in which as course director I had no obvious stake) including: *What have been the high points of the project/placement? What have **you done** that you remember most clearly? What have **you said** that you remember most clearly?* In summary, I sought to balance my desire to research the process of learning which my own students were engaged in with the necessity to undertake that research in a systematic and valid manner.

The schema

The early stages of the study were characterised by my ill-formed theoretical background, changing aims of the study and logistical problems of the transcription of interview tapes. After this unstable and largely unproductive period my aspiration became to code the transcripts and to seek to place these individual units of meaning into the larger frame of a typology. A number of different typologies evolved from early analysis of data but their purpose remained constant. I saw the typology as a 'map', an analytical tool, by which I could identify the categories of meaning, and their relationship, that respondents used to understand their actions in learning settings. Although the detail of these different typologies changed, their overarching principle of 'intention' remained stable.

I came to comprehend that all respondents experienced a tension between two contrasting intentions when engaged on design and technology project work in a learning setting. On one hand in their 'doing' of design and technology they were seeking to make change to the made-world; the world of products and systems. In this mode they were acting as designers; they were *designing*. On the other hand they were doing this design and technology within a course that led to a qualification and thus they were seeking to learn; to make changes to themselves. In this mode they were acting as learners; they were *learning through designing*. Additionally, my analysis indicated that these intentions, whether 'designing' or 'learning', could be directed to either themselves ('self') or outside of themselves ('other'). As I struggled with this tension in the data, ideas crystallised to form an 'analytical tool' to help reveal understanding of the respondents' transcripts to myself. I saw it as having the potential to represent succinctly the major dimensions and domains of interaction and I came to use the term *schema* for this analytical tool. I use the term here as a model representing the structuring of generic concepts which is used and tested as individuals face a situation. At the time of the fieldwork that this paper utilises, the schema had been finalised, Figure 1:

but more importantly there had been a transition of power and responsibility from researcher to respondent. At an earlier stage of the research, I asked questions and respondents' involvement was in giving answers to those questions, however semi-structured those questions might be. Respondents now used the schema as a reflective tool for themselves prior to an interview. An example is given in Figure 2 of another respondent's use of it in another fieldwork location.

The schema uses four terms, two of which, learning and designing, were problematic for the respondents. It became increasingly clear that the schema had the potential to prompt respondents to reflect on their meanings for these terms and to access these meanings was central to the aims of the study. A more detailed account of the process of evolution of the schema, both its configuration and its purpose, is given in Elmer (1998).

Meta-cognition 'in action'

Case study is a frequently used approach (sometimes incorrectly termed a methodology) in research generally and educational research in particular. It is aimed at understanding practice in all its complexity and places emphasis upon reflection and deliberation, on context and meaning (Fish, 1998; Bassey, 1999). Golby (1993) argues that properly conceived, case study is uniquely appropriate as a form of educational research for practitioners as it is 'synonymous with professional activity; it is what professionals do day by day.' (*ibid*: 11) It is not a study of uniqueness but of particularity and although small scale a case study like a poem, painting or a piece of music can carry important truths to its audience (McDonald and Walker, 1977). The following case is concerned with seeking to identify meta-cognitive activity in a design and technology setting. I commence with some contextual detail: the briefest of

Figure 1: The schema.

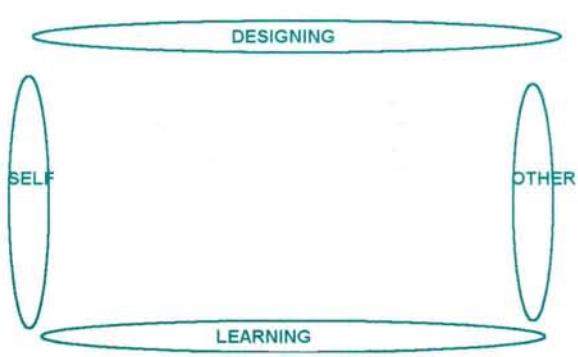
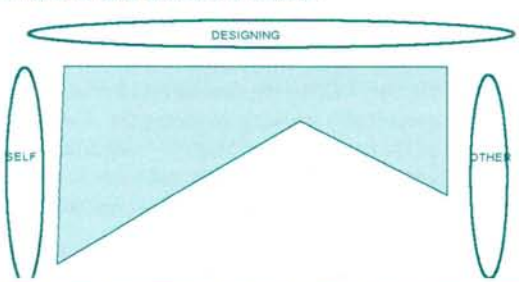


Figure 2: One schema sheet for Iain Williams placed alongside sections from an interview.

Iain's schema sheets completed during the week prior to the interview.	Sections from the interview. [Int, Interviewer. IW, Iain Williams]
Schema 2 If my intervention in the made-world is to be worthwhile doesn't it have to take account of others?  	Int. What's happening here? IW. Really after some more thoughts I realise that if my intervention is to be worthwhile how can I not include other people? [...] I thought if I was going to design this table or whatever it is, if only my legs are going to go under it then it's not going to be very beneficial to millions of other people who are taller than me. [...] I guess a lot of my previous project work was very self-centred, when you bring in this notion of others it seems so obvious, but I don't think I really thought of it as others [...] I see design as being beneficial to all.

biographies of Mark Skinner; the Major project; the intentions of the fieldwork.

Mark Skinner

Mark's school career was conventional; a comprehensive followed by sixth form college. Less conventional was that from 16 he had worked part time as a tattooist and after sixth-form he continued this full-time. At 24 he became a 'paste-up artist' on a London daily newspaper and at 29 he commenced the BA.

The Major project

The Major project was programmed over the final two terms of the fourth, and final, year of the course. It was seen by students and tutors as the culmination of the degree course and the means to exhibit the full range of students' design and technology capabilities. It constituted a major part of not only the fourth year but the whole course assessment. As it was individually negotiated it allowed a student's individual enthusiasms to be developed to a high level.

Interview

I undertook five research interviews with all eight respondents over the period of the Major project but this case draws on only the first interview with one respondent. Mark was not unique, all respondents exhibited meta-cognition strategies to greater or lesser degrees but Mark was chosen as one of those in whom these were well developed. Mark had been using the schema since midway through his third year. The case account is presented in the form of my commentary interspersed with quotations from the interview. The full interview transcript runs to 4,000 words. The intentions of the first interview were to explore the early stages of the Major project, and specifically:

> 'At the outset, how have intentions for the Major project been identified?
>
> Can you think of anything that has influenced you identifying these particular intentions?
>
> Have there been any changes to your intentions since you've started thinking about the Major project?
>
> Can you think of anything that has influenced these changes of intentions?'
> (section of Interview Schedule)

First interview: the early stages of the Major project

The major intention determining Mark's approach to his Major project was to meet course requirements and, specifically, course assessment. In order to achieve this overarching intention, Mark generated three sub-headings of research, design process and the displayed artefact, against which any potential project that he identified could be interrogated. Once an idea fulfilled the criteria inherent in these three categories, it could be considered and analysed further using additional categories of: personal interest; working to strengths; values.

The first potential project was concerned with chip-pan fires. Against the requirements of his first category of research, he realised that he would be dealing with subjective data and this was an area that he felt uncomfortable with:

> 'How do people perceive a product? How do they feel about it? It's more to do with people's personal feelings, understanding these at the commencement of the project and that was what I was trying to capture and I found problems with this project.'

As for **Design process**

> 'It was a go nowhere project and I wasn't getting these jumps of imagination ... it was based upon a solution and that was the error.'

The project had considerable **Display** potential but by this time the project had been rejected.

The second potential project was for dispensing of medication. The project started from a desire to show technical knowledge and understanding, thus meeting the **Design process** category.

> 'I thought I'd like to do an electronics project. It's cheap and quite interesting. I wanted to prove my knowledge or understanding of logic, to start incorporating relatively complex electronics which were operating a controlling system.'

The **research**, although not defined, seemed to hold potential, but it was the third category – the final display, that raised concerns in Mark's mind.

> 'How I was going to collate all the information and thinking and design work and actually show it to someone and say 'this is the design process I've been through' and illustrate it was going to be a bit more difficult ... lots of bits of electronics scattered across the tabletop.'

He now utilised the second set of criteria, specifically **working to strengths**. The nature of the need required Mark to work less in areas of personal strength and more in weaker areas, and in particular end user research.

> 'And it moved too much out of my field. It didn't allow me to illustrate any of my

> strengths. The whole time I'd be working to weaknesses.
>
> I: What would you perceive those weaknesses to be?
>
> The project turned out to be very heavily biased on end user research. It's a failing of mine, but an area that I struggle with. I'm happier dealing with quantities. I can analyse them and work methodically and put them in pigeonholes. This one was immense for lots of other reasons. It meant contact with so many different parties.
>
> I have to say that I've developed almost a phobia of end user research and I find it's this business of imagining a product being used in an imaginary situation. What I want to do all the time is say 'That's fine, but I want something concrete.'

The project has potential with regard to **values**, and Mark's own learning (interest), but the latter may not be accessible to the assessors of the project.

> 'It's a very worthwhile project and fulfils lots of humanitarian needs. Where this one falls down is that there's a very grave danger that it would have been difficult to illustrate that to every lecturer. At the end of the day it was not the best vehicle to allow me to get a degree.'

The third potential project was prompted by an industrial placement that Mark had just completed. Raleigh PLC had an electronic scooter in the office but they had insufficient time to develop it. Coventry University industrial design students were invited to help Raleigh with this development work and Mark had been asked to write the brief for them. This role-reversal caused him to consider the project.

> 'The week I spent on that then made me analyse how I would myself attempt this project and being in an odd position in actually dictating to other students, it put the product in a different light ... it was being taken out of it slightly and I thought 'I'm not going to do this project, but how would I do it?' and it immediately managed to break it down into these segments of work and equate it against time and write a brief and generally start to explore it at a different level. Very loose, but these three bands again.'

As to his first category, **research**, and particularly with regard to end user research there was a tangibility to it, something concrete:

> 'I had an instrument which was to be developed. I could take this scooter out and ask people what they thought, they could ride it, I could gain impressions and build up this picture ... I had a base, a natural, easy plottable progression. Fine, the end user research looks good.'

The **design process** category has potential and particularly; variety of approaches, mechanisms and power sources which are *quantifiable*.

> 'It directly comes back to how many amps per hour the battery produces. It's very quantifiable. In some ways I wouldn't say it's an engineering based project, but it's things that I can apply figures to and when I work this problem through I feel very confident in producing the data and explaining why I've come to conclusions.'

The end product on **display** had great potential, both if it is complete:

> 'It should display well. It can be backed up by graphics.'

and if for any reason only part (s) of the project are complete at the time of the display (not all eggs in one basket) then personal achievement is still possible. This is a strategic approach showing a fall-back position – if I don't do this, then the display e.g. course assessment, still has potential of achievement for me.

> 'The project didn't have a fail point. If I didn't reach the perfect end result I could research it and if things went very badly I could produce a model which would be backed up with sound information to say why it was like that. If things were running better and progressing I could make a very rough working model which people could test and get a feel for it and then reinforce this with graphic images which I feel more confident I could produce quickly to give it this 'OK, here's the concept. This is what it's going to be like when it's styled' and my third and real hope behind this is that everything goes completely according to plan and I actually manage to get a styled, finished object.
>
> ...I'll be going with because it had the excitement of the other projects, but also a sense of safety. I know there's an achievable end result which is displayable.
>
> ...It **talks** through the three [categories].'

Discussion

The discussion examines whether Mark is exhibiting meta-cognitive activity. Meta-cognition is an emerging and contested ground. Flavell (1976, 1977, 1981) would be seen by many as a seminal influence but increasingly there is a tendency to describe

and explore its attributes within a specific subject domain (Schoenfeld, 1985) (Otero, 1996). It is possible, and perhaps proper, that at a later date there will emerge a view of 'meta-cognition in design and technology education'. It is not my intention to engage in a critical review of the literature but rather to establish a few core principles from which this paper's discussion might proceed. To characterise meta-cognition as 'Mind having knowledge of itself' or 'thinking about one's own thoughts' is insufficiently precise. Flavell (1978) proposes that meta-cognition is multi-faceted and includes knowledge about strategies, tasks and the self, as well as the skills to evaluate strategies Hacker *et al* (1998) believe there is a general consensus that meta-cognition should include these attributes: knowledge of one's knowledge, processes, and cognitive and affective states; the ability to consciously and deliberately monitor and regulate one's knowledge, processes, and cognitive and affective states.

Mark has three clear categories to assess the potential of his ideas for the Major project and these categories are directed to one aim, his achievement on the course. If any potential project meets all these criteria then a further set of assessment categories are utilised. Mark displays clarity of overall intention and the criteria to evaluate whether potential 'vehicles' are suitable. A refined and conscious strategy is used. Rather than using a large number of criteria at the outset, which could be unwieldy to use, there is one small set. If an idea passes these then a second set comes into play; it is a strategy of progressive filtering. This thinking needs to be, and is, carefully and finely balanced. Research is an exemplar of this thinking. Mark believes that research should entail end-user research and he believes his assessors believe it should. But Mark is not comfortable with doing end-user research (Flavell's [1979] knowledge of self). He must therefore manage his intentions such that research is done, and done *properly*, but with a minimum of end-user research. *Properly* means meeting both Mark's values and the values of his assessors. Mark's values of 'personal interest' and 'meeting human need' are in conflict with 'working to strengths'. He wants the project to meet human need but this underpinning value is in conflict with his main personal intention of achievement on course because of the difficulties of engaging in end user research. He examines alternative courses of action associated with this dilemma and chooses between competing possibilities using clear criteria.

Summary

Mark is able to see that the Major project, as any design and technology project, is not a given but a construction; not a construction of wood, fibre-glass, etc. but a construction of intentions. Some intentions are generated by others (assessment criteria of the Major project) but others are generated by himself. This complex inter-play of intentions is resolved by Mark creating an envelope of project intentions that are directed to achieving his overarching personal intention but which minimise conflict between other values. I suggest that Mark is exhibiting two essential features of meta-cognition, that of self-appraisal and self-management of cognition (Paris and Winograd, 1990). Self-appraisal in his ability to reflect not only on his knowledge and skills but the affective dimension of that knowledge and those skills, in particular their motivational characteristics. Such reflections answer questions about '*what* you know, *how* you think, and *when* and *why* to apply knowledge or strategies (Paris and Winograd, 1990: 17). Self-management is his ability to deploy cognitive processes to orchestrate his actions.

If we as practitioners/commentators/'product champions' believe in the importance of meta-cognition in design and technology, then there are a number of unresolved questions that need to be addressed. This paper has sought to explore two of them. Firstly, how confident are we in identifying meta-cognition in practice (what does meta-cognition look like, sound like, feel like, smell like in a design and technology *milieu*). Secondly, how can we develop and promote it further in learners? It is my intention that a subsequent paper will continue the story of Mark into his present professional setting and address a number of issues raised here but not answered; for example, the relationship between reflection and meta-cognition.

At one time I commenced or finished many documents, particularly design briefs for students, with a line of poetry. I have weaned myself mostly from this habit unless I believe it to be particularly insightful.

> 'How can I know what I think until I see what I say.' (Auden, 1962)

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References

Archer, B. (1979) *The Designerly Approach to Knowledge Lecture Course*, London: Royal College of Art

Archer, B. (1982) *Cognitive Modelling, Rational Thinking, Language, Designerly Thinking and Imaging*, Internal Paper, London: Department of Design Research, RCA

Archer, B. (1992) 'As complex as ABC', in Roberts, P., Archer, B. and Baynes, K. *Modelling: the Language of Designing, Design: Occasional Paper No. 1*, Loughborough: Department of Design and Technology, Loughborough University

Auden, W.H. (1962) *The Dyer's Hand and other Essays*, New York: Random House

Barlex, D. and Pitt, J. (2001) *Interaction: The relationship between science and design and technology in the secondary curriculum*, London: Engineering Council

Bassey, M. (1999) *Case Study Research in Educational Settings*, Buckingham: Open University Press

Cross, N. (1990) 'The Nature and Nurture of Design Ability', *Design Studies* 11, 3: 127-140

Dewey, J. (1933) *How We Think* (Revised edition, originally published 1910), Boston: DC Heath

Dewey, J. (1938) *Experience and Education*, London: Collier-Macmillan

Eggleston, J. (1996) *Teaching Design and Technology*, Buckingham: Open University Press

Elmer, R (1996) *Whose need? A study of reflective practice of eight students on a BA (Hons) Design And Technology course* unpublished PhD thesis, University of Reading

Elmer, R. (1998) 'Probing Intentions of Design and Technology Students', *International Journal of Technology and Design Education* 8, 3: 221-240

Fish, D. (1998) *Appreciating Practice in the Caring Professions: Refocussing professional development and practitioner research*, Oxford: Heinemann

Flavell, J.H. (1976) 'Metacognitive Aspects of Problem Solving', in Resnick, L.B. *The Nature of Intelligence*, Hillsdale, NJ: Lawrence Erlbaum

Flavell, J.H. (1977) *Cognitive Development*, Hillsdale, NJ: Lawrence Erlbaum

Flavell, J.H. (1978) 'Metacognitive Development', in Scandura, J.M. and Brainerd, C.J. (Eds) *Structural/Process Models of Complex Human Behavior*, Netherlands: Sijhoff and Noordhoff

Flavell, J.H. (1979) 'Metacognition and Cognitive Monitoring: A new area of cognitive developmental inquiry', *American Psychologist*, 34: 906-911

Flavell, J.H. (1981) 'Cognitive Monitoring', in Dickson, W.P. (Ed) *Children's Oral Communication Skills*, New York: Academic

Golby, M. (1993) *Case Study as Educational Research*, Exeter: Fairway Publications

Hacker, D.J., Dunlosky, J. and Graesser, A.C. (Eds) (1998) *Metacognition in Educational Theory and Practice*, New Jersey: Lawrence Erlbaum

Harrison, G. (2001) *The Continuum of Design Education for Engineering*, London: Engineering Council

Hennessy, S. and McCormick, R. (1994) 'The General Problem-solving Process in Teaching Education: Myth or Reality?', in Banks, F. (Ed) *Teaching Technology*, London: Routledge in association with Open University Press

Kelly, A.V., Kimbell, R.A., Patterson, V.J. and Stables, K. (1987) *Design And Technological Activity: A framework for assessment*, London: Assessment of Performance Unit/HMSO

Kimbell, R. (2001a) 'Design and Technology and the Knowledge Economy', *The Journal of Design and Technology Education* 6, 1: 3-4

Kimbell, R. (2001b) 'Engineering Influence', *The Journal of Design and Technology Education* 6, 1: 99-100

Kimbell, R., Stables, K., Wheeler, T., Wosniak, A. and Kelly, V. (1991) *The Assessment of Performance in Design And Technology*, London: Assessment of Performance Unit/HMSO

Kimbell, R., Stables, K. and Green, R. (1996) *Understanding Practice in Design and Technology*, Milton Keynes: Open University

Kimbell, R. and Perry, D. (2001) *Design and Technology in a Knowledge Economy*, London: Engineering Council

Lawler, T. (1997) 'Exposing and Improving the Metacognition of Designing through Practical Structured Workshops', *Proceedings of IDATER 97 Conference*, Smith, J. (Ed) Loughborough: University of Loughborough

McDonald, B. and Walker, R. (1977) 'Case Study and the Social Philosophy of Educational Research', in Hamilton, D., Jenkins, D., King, C. (Eds) *Beyond the Numbers Game – a reader in educational evaluation*, London: Macmillan

Otero, J. (1996) 'Components of comprehension monitoring in the acquisition of knowledge from science texts'. In Fisher, K.M. and Kibby, M.R. (Eds) *Knowledge Acquisition Organisation and use in Biology*, Berlin: NATO-Springer-Verlag

Paris, S.G. and Winograd, P. (1990) 'How Meta-cognition can Promote Academic Learning and Instruction', in Jones, B.F. and Idol, L. (Eds) *Dimensions of Thinking and Cognitive Instruction*, New Jersey: Lawrence Erlbaum

Ritchie, R. (1995) *Primary Design and Technology: A process for learning*, David Fulton: London

Schoenfeld, A.H. (1985) *Mathematical Problem-solving*, New York: Academic Press

Schon, D. (1985) *Design Studio: An Exploration of its Traditions and Potential*, London: RIBA Publications

Shirley, M. (2001) 'Foreward', in Kimbell, R. and Perry, D. *Design and Technology in a Knowledge Economy*, London: Engineering Council