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An exploration of design thinking across educational domains.

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Abstract: *To teach design effectively foundational design thinking needs to be understood. Treating the design process as a mysterious mental talent provides little scope for teaching the subject. This study explores the origin of designs and how experience impacts the sophistication of design ideas across educational domains. Secondary and tertiary students were given a common architectural brief and students' outcomes were compared and contrasted to seek commonalities or differences in their approaches to solving design problems. Additionally, interviews were conducted with participants and a panel of design experts to further explore the students' design practices. The results provide insight into design cognition from multiple viewpoints. We argue that designs come from various forms of copying; metaphors, analogies and icons are used as preconceptions by which a design problem is understood. Moreover, experience had a direct link to expertise which is evident across educational domains.*

Keywords*: design, cognitive process, secondary education, motivation.*

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Introduction

Learning to design is like learning to speak. Anybody can do it, but it can be enhanced by an understanding of the mental processes that allow us to generate form. It would be difficult to find any design educator who went out of their way to disable or disengage students. The by-product of informed practice is arguably our ultimate goal; better designers (Cross 1990). But in order to grow design minds we must understand how they work. Not just at the end of the spectrum but progressively, from the novice right through to the visionary (Dreyfus 2003a; b). With the growth in literature around design thinking it would seem that no matter where your students are within this spectrum there is scaffolding to assist your teaching practice. However, educators are faced with a stumbling block that has been lingering since the late 1960's: polarised views on the nature of the design process itself. The two main views derive from: (i) a phenomenological approach where design is seen as a way of constructing knowledge, and (ii) a scientific approach based on optimization theory where design is a process to reach an artefact (Simon 1969).

The first approach acknowledges that design differs from other forms of problem solving due to the parallel problem/solution relationship undertaken by the designer (Cross & Dorst 1998; Cross & Dorst 2001). Design problems, described as ill-defined problems (Cross 2001a), require an approach that is based on the production of partial solution conjectures to aid problem solving. An inter-dependent relationship between problem and practice is regarded as an integral part of design development. The second approach, known as Design Theory or Design Science, is an iterative process that is cyclic in nature and follows a prescribed formula to reach an end product. The cycle includes prototyping, testing, analysing and refining, and is intended to improve the quality and functionality of an outcome; feed in information and out comes a design (Cross 2001b; Cross, Naughton & Walker 1981).

It is commonly claimed that this method fell out of favour in the 1970s because the iterative process failed to account for the generation of form and could not objectively solve 'wicked' problems (Rittel 1972). Wicked problems are those problems that require a partial solution in order to be solved. Despite being discredited, iterative processes still prevail in teaching practice and curriculum development, especially at secondary school level and can result in a disincentive for students to engage (Wells 2010).

This study has been driven by the concern that design educators and those developing curricula are divided in their understanding of the nature of design thinking and how it should be best supported by design practice. It is of particular concern that stages of design education could be hindered if institutes such as secondary schools and universities have not established common ground about something as fundamental as where design ideas come from and how to develop design thinking. Without such collaboration institutes could be unwittingly working in opposition.

This paper presents the results of a comparative study between secondary and tertiary design students who underwent a common design project. Qualitative data was also gathered from participant interviews. The use of a common architectural brief provided insight into the practices of design students across educational domains and enabled the exploration of how experience influences design solutions.

A model of expertise

Despite the breadth of literature available on design expertise much of this research investigates design students engaged in tertiary study or noted expert designers (Cross 1990; Cross & Clayburn Cross 1998; Dorst & Reymen 2004). We saw this as an opportunity to compare students at the beginning of their formal design education to those about to complete an undergraduate degree. The available research is extensive enough to assist design educators in making judgments about their students' levels of expertise by being able to recognise traits associated with novice, through to expert, designers. Several studies have made a significant contribution to the field of expertise in design (e.g. Atman & Chimka 1999; Dorst & Reymen 2004). Dreyfus (Dreyfus 2003a; b) proposes a model where acquired expertise can be scaled from novice to visionary, a model endorsed by Dorst and Reymens (2004). This model is skill based and "distinguishes seven distinct levels of expertise, corresponding with seven ways of perceiving, interpreting, structuring and solving problems" (Dorst & Reymen 2004, p. 3). Dorst and Reymen (2004, p.1) note that there is still little known about "how to stimulate design expertise development". Our analysis of expertise is based on the Dreyfus model (Dreyfus 2003a; b) with secondary students hypothesised as 'novice' and tertiary students as 'competent' and 'proficient'.

Methods

The use of a common design brief was integral to our study. We wanted to have authentic, visual evidence to exemplify ideas and expertise. Students worked through this brief using the typical practices, pedagogy and assessment of their respective teachers and institutes. Both secondary and tertiary participants were aware that they were following a common brief but cross pollination was not permitted. Samples of the completed design projects were collected and analysed; five from secondary students and four from tertiary students. Using Broadbent's (1973) classifications to seek the origin of the generation of form each initial concept was placed in and across Broadbent's (1973) four categories using a table and point scoring system. Each design sample was allocated five points that were awarded to specific categories depending on the evidence present. Categories have been labelled as such; P= pragmatic, I = iconic, A = analogic, C = canonic.

A series of interviews were then set up with the participants and all of the design samples. It was important that participants were able to speak to their work and compare it to other samples. Secondary students were interviewed together and one tertiary participant was interviewed. An interview with a panel of experts who spanned educational domains and industry was also conducted. The expert participants all had sound understanding of design research, education, theory and practice. The interviews were informal and discussion based and while the questioning was similar for secondary and tertiary groups the resultant discussions followed different trajectories. Student participants were asked to comment first on their own work, specifically successful attributes of their outcome and what they would change given the chance to re-do the project. They were then asked to comment on the work of students from the other educational domain, identify similarities and discuss the design brief and any other specific challenges they encountered. There was additional discussion with the tertiary participant about the progression the participant had made from secondary to tertiary level, and how she foresees gaining employment as a designer. The expert

panel discussed the samples, nature of their own design practices and design education, and the progression design students may make from study until professional practice. Participants were given the option of contributing additional comments at the end of each interview. Each participant has been allocated a code to differentiate individual responses throughout the interviews. The letter represents the interview group, S = secondary T= tertiary and E = Expert. As there is only one participant the tertiary student has not been given a number. The coding was allocated randomly and has no additional meaning other than differentiation.

Results and discussion

The generation of form

The ability to classify each sample using Broadbent's categories is suggestive that architectural form is derived from a pre-conceived notion. The interview data only reinforces this with participants not only being able to account for the origin of their ideas but also the way these ideas are developed. The use of the partial solution-conjecture to solve design problems as suggested by Cross (1990, 2001a; N. Cross & Dorst, 1998, 2001) was apparent in all participants, along with the rejection of an iterative design method as a representation of true design practice. The unanimous rejection of the idea that design is practiced by a prescribed iterative process (N. Cross, 2001a; Rittel, 1972; Roberts, 1982) is important as it questions many current design education practices.

Expertise across educational domains

Participants sat comfortably within the model proposed by Dreyfus (Dreyfus 2003a; b), the interview data supported our conclusions. The secondary students were driven by an overall focus to 'make it work'. This being said, there was evidence that some participants had elevated themselves form 'novice' to 'advanced beginner'. However, the inability to fully communicate and resolve their ideas prevented them for working at a 'competent' level. Solving design problems came at a high cognitive cost as they had very little tacit knowledge to apply to the situation, hence their need for rules and data from experts and stakeholders.

The tertiary participants were operating in a different way. With less of a cognitive cost they were able to approach the brief from a conceptual standpoint. They were able find guiding principles and tap into relevant research and practices to inform their design ideas. They were involved emotionally in their concepts and participants appeared to have delved beneath the surface of the design brief. Some of the tertiary participants may have been working at a 'proficient' level, but without having interviewed them, we cannot be certain.

Interview data

The interviews have provided rich unedited commentary from multiple perspectives. As the aim of this study was an exploration of design minds at different stages we feel it is important to include as much of this commentary as possible; we have let our participants do the talking throughout this section.

CRITIQUE OF SAMPLES

Secondary participants used functionality and their ability to meet the objective specifications of the given brief to describe the strengths of their final design. The depth at which they could discuss this was impressive. It suggests where secondary students place importance when it comes to solving design problems. This passion for functionality was a strong reoccurring theme throughout the interview. Participants all spoke of their outcome as being interesting or successful because they believed the form was different or innovative. However, most were unable to elaborate on how design principles or philosophies may have guided the development of their form. They were aware that their drive for functionality had been at the cost of subjective aspects such as aesthetics and form and spoke of their ignorance in relation to the treatment of and use of three dimensional spaces.

> My building has a double wall cavity and that houses the wind turbines. This means that you don't really see them because I didn't really like the look of the wind turbines on the outside. The wind is funnelled through and that can be used for ventilation for the inside as well, and I can collect rain water and I've got solar panels all over the roof. I think my courtyard is quite good because it's sheltered on the inside from all the wind and everything. (S1)

When asked to describe the success of her design, the tertiary participant's answers differed substantially from the secondary responses. She believed her success was in her ability to respond to the overarching concept of the brief; sustainable architecture. Her design process was underpinned by her understanding of what sustainability was in a wider sense and where it could be taken.

> Well I think I looked at light, and I really like the way the wind catchers actually well, catches wind. Also providing light, it's like multifunctional, like one thing offering a whole lot of things that matter at the roof top and also the form. I think being quite simple is nice, other people doing the same brief are using quite high technology stuff that may work one way or another, but sustainability doesn't have to be like, using high tech machines to generate it because we have such a long history of building simple stuff but still being able to live comfortably. (T)

Secondary participants noted research and design process as the major similarities across the design samples. Presentation was seen as the major difference. While they were not intimidated by the tertiary samples they were surprised at the level of creativity and the evident sources of inspiration contained within the tertiary design work.

> I didn't they'd be so creative. (S3)

> Yeah I thought it would be simple as form. (S4)

> No I didn't think it would be simple form, I just didn't think they'd be so like, kind of different but normal. Like, you can see where they got their inspiration from. (S3)

> You can see where they have come from. (S1)

When asked to describe changes or refinements to the final outcome the tertiary participant spoke at length about how she believed in her guiding concept of light and creating a space to influence the behaviour of workers. She did not, however, feel like she had fully resolved all of the practical problems associated with her concept. Unlike the secondary participants, the tertiary participant was comfortable with submitting

the final outcome without having solved the more functional aspects of the common brief because she believed her concept was strong enough. She was also able to identify a significant difference between the secondary and tertiary solutions; the secondary solutions had failed to integrate functional aspects such as turbines and water collection with the form of their buildings. The participant also noted something the secondary samples openly admitted; the lack of guiding principles in relation to the development of their form. The overall outcomes and presentation of ideas came as no surprise to the tertiary participant and she spent some time musing over her own secondary school design experiences. She identified her greatest challenged was working with a realistic approach and solving structural issues. She was also challenged by the nature of the brief; architecture at an extreme altitude.

The expert participants were impressed with the quality and variety of design thinking and solutions present within the samples. The discussion of the samples themselves along with being able to identify student risk taking caused much excitement. There was specific reference to how the secondary students in their self-aware ignorance and naivety were desperate to gain as much functional data as possible and thus generated high level questions that the tertiary students had potentially overlooked.

> It was a few weeks that you introduced this project to your students you came to me with a list of questions, really long list and it was so impressive, the questions they were asking were so much better than my own students, it was unbelievable. A lot of them are very down to earth, 'do we need a fire escape?' and things like that. I don't think any of my students would add a fire escape. (E3)

The experts regarded the brief as challenging and exciting and were impressed with the tenacity at which all students had attempted to solve testing design-problems. They encouraged students being presented with such big issues, especially in relation to the relevance of such problems to the world of design. Like the tertiary participant sustainable architecture or sustainable design was not seen as a 'doom and gloom' subject but an exciting opportunity.

> To me I'm excited by it because it's rarely I see a brief given to school students that really challenges them beyond a house on a ground level. There are some real nitty environmental challenges here which to me are all about making the designer think about sustainability and the footprint they leave on the earth. You know looking at the wind and the rain and we sometimes think that kids can't cope. They can design but making them think about the design and why they're doing it is hard, so I like the fact that you've challenged these kids. (E1)

SOLVING DESIGN PROBLEMS: THINKING AND PRACTICE

This section sparked impassioned responses by the secondary participants, particularly in regard to drawing and personal versus prescribed design practices.

> Well I didn't really start off with a solid design at first. I changed the design at least five times before I came up with the mushroom and after getting the feedback (from a stakeholder at university) I realised it's not really much of a building, it's more of a fantasy, I need to squash it down into a building that could work hopefully, and it just took a long time to actually figure out what it was and to find a different and innovative shape. (S2)

Commonalities surfaced after they were asked to be more explicit about how they generated their initial ideas. Secondary participants were very clear about the amount of time spent solving design problems in their minds rather than on paper. It was not until they had come to some kind of resolution point did they then transfer these partially solved solutions to paper to develop further. Strict and rigid design tasks based on an iterative design process, they claimed, can actually harm design work.

> Sometimes your first outcome can be your best. When you start developing it you're going more towards the specifications, but you're going away from the whole brief in some ways and you've lost the whole creative part. (S4)

> That's real annoying if you think of something mean as your first idea and you think of like six other crap other ones. (S3)

A re-occurring and dominant theme was the importance of being able to transfer mental images to paper and participants' frustrations when not able to do so. When asked to elaborate on confidence and quality of drawing students admitted that it was a stumbling block and without direct instruction and visual success it pigeon holed their ideas.

> The drawing course helped me a lot because after doing it I did notice that my drawing had improved with free objects and stuff, before that it was just pants. It was horrible but after that course I could actually look at my drawings and not be ashamed. (S2)

The tertiary participant stressed the ability to access and use inspirational material along with site analysis in order to generate form and develop ideas. Through investigation she was able to source guiding principles for her work. The use of quick sketching to capture design ideas and constant feedback and communication with tutors helped her to refine her work.

> I do sketches first because it's quicker. I can just think and draw. I sketch and then I talked to Alfred and we find more. I think inspiration from existing work and from internet is really important because sometimes you look at something and just go "oh" or "you can do it like this" where you never know if you don't see it. So when I get stuck on the computer or anywhere I ask for like books or resources then you can always sort of find some more information, inspiration. We just keep on talking, communicating. (T)

The expert participants were bothered by the presentation of some of the samples, particularly the secondary samples. The architects were especially disheartened to see the rigid and iterative process the secondary students were required to produce, and felt it did not complement authentic design practice. One participant was appalled at the suggestion there may be a standard operating procedure employed in order to create design solutions in general.

> It's interesting what you say about concepts where you've got to have three or four different concepts because if it's one that you're really passionate about that should be it. But maybe it's almost that pre-concept and it's that balance between what you were saying about the kids that were happy to do the research but couldn't jump into putting something on paper. The research needs to inform, almost like a pre-concept and then maybe it's something to do with that. (E5)

Confidence was identified as being crucial to success. Expert participants spoke at length about how lack of confidence can cripple a designer and how it could be nurtured within design education. Confidence, they believed, can enable a designer to take risks and to stay true to ideas, and therefore having a large bearing on the nature of the outcomes produced. Creativity and creative thinking was discussed as sitting alongside confidence. Participants were passionate about the encouraging students to feel like they are in a learning environment that celebrates and honours creative thinking. They expressed remorse that creative thinking seemed to get squashed in the secondary system and spoke about building resilience into design students to avoid this from happening.

DESIGN EDUCATION: DEVELOPMENT OF EXPERTISE

Secondary participants were asked how they could have been assisted to extend their initial generation and the development of their form. Potentially helpful tools included things such as visits to architectural sites, practice, practical and functional data, and to work in parallel with the tertiary students. They noted that experience in both objective and subjective areas has a bearing on the degree of sophistication to which design problems are solved.

> Probably a bit more research into buildings or maybe even going out and seeing some buildings like rather than you're researching things that you know, like kind of, you're typing in words that you kind of already know and you've already seen. So if maybe we went out or to some exhibition or something like that and saw different examples of architectural buildings and might have a different idea of what to do. (S4)

Secondary participants spoke of the need for inspiration coupled with a place to exercise their own original and creative thought. Feedback featured strongly, with participants stressing that this project was far better as it had links outside the classroom and contained real stakeholders, and that quality feedback from classmates, educators and stakeholders makes a positive difference. Overall participants were in agreement that collaboration would be a positive thing for both secondary and tertiary students. There was mention of feeling uncertain initially but now participants were glad they had been given this opportunity.

> I think it's interesting that alongside the university people, because it was a bit more of a challenge to see how well my work would compare with them, because they've got all this greater amount of instruction from their specialised lecturers who have experience in field work and have all this somehow infinite knowledge, and I really wanted to see how well my work would compare with their work. But of course their work is slightly better because it's all computer graphics and presented really awesomely with lighting conditions and stuff. (S2)

The tertiary participant's experience of design at secondary school greatly differed from her experience at University. Differences included the nature of the teacher given design brief, the kind of communication offered by educators and the way in which design thinking and solutions were presented. The tertiary participant felt secondary school had not prepared her for architecture school and noted she did not fully understand what she was getting herself into when enrolling in the course. The ability to stand up to critique came through loud and clear as a way to both extend and prepare secondary students for architecture school. The participant also made mention

of exposing secondary school students to architecture and architectural practice. She could clearly see how tertiary education had extended her as a designer. She suggested that additional experiences such as site visits and exposure to more 'stuff' may allow for further extension of design expertise. As with the secondary participants, the common brief did spark curiosity from the tertiary participant, though not quite as much due to her ability to recall her personal design experiences. The participant also agreed that collaboration between secondary and tertiary was a good idea and thought that collaboration between tertiary and industry could help students find employment.

> I heard in some other places maybe Europe I don't know or China for instance to co-operate with universities during summer or even during the year. You can go there say once a week and then do something. If you're good then they can contract you after you graduation which is good, saving you time to look for a job. And also with that experience within university years you think much more like a real architect instead of just thinking concepts and ideas, you think about how to build it and how to make it happen. (T)

Four key areas were identified by the experts: (1) explicitly encouraging creative thinking, (2) bringing student interests into the classroom, (3) building on existing knowledge and (4) growing passion. The concept of perception and learning to see arose from one participant who had been listening to how life experiences help to inform design practice and links to the development of passion. All participants agreed an important facet of design teaching should be perception; that is, learning to see and to observe and being able to channel that inspiration. The ability to communicate ideas was discussed at length. Participants noted that design students should be given the opportunity to practice being able to present with confidence and competently use different modes and media to do so. As in the tertiary interview, the ability to stand up to critique was seen as a vital attribute for a skilled designer to possess.

> That's what I want to jump in, it's that observational factor. Who teaches these kids to actually look at things? We don't teach our students how to observe. We jump in too quickly I think, "here is the brief" but have we actually opened their eyes to new ways of looking and thinking first? (E1)

Expert participants were asked to discuss their views on collaboration in general, but also between secondary and tertiary domains, and tertiary and professional practice. They, like all other interview participants, saw collaboration as a positive step for design education in New Zealand and the wider design community. They did note that it was not going to be an overnight reality as there are rigidly established cultures involved in education.

Limitations

This study has some limitations: the small sample size, lack of quantitative data, the gender breakdown of the secondary participants and the sample size of the tertiary interview participants may limit the generality of our findings. However, as an exploratory paper, we believe that it has been successful. Despite the study's limitations there are a number of commonalities throughout the responses of the participants. These findings have been articulated without coercion, often with great conviction and reiterate a good deal of current design literature on the nature of design thinking and problem solving. We believe the findings from this study are too important to ignore, especially in regard to design education. More research needs to be done to

scaffold these findings but the first step has been made, and the time is surely nigh for such professional dialogue.

Conclusion

So what can we do then to grow our designers and develop their expertise? We will have to adjust the way in which we educate them. It has been illuminating to see things spoken by fifteen-year-old school students reiterated by sixty-year-old professionals, and how these responses link with design literature.

Confidence, perception, collaboration and experience seem to encapsulate the thoughts of the participants. They suggest that design classrooms should celebrate creative design thinking and nurture confidence. These ideas are promoted explicitly by Spendlove (2007a; b), Wells (2010) and Cross (1997). Confidence could be greatly aided by students being able to see that their ideas have worth and possessing the ability to communicate these ideas. Students need to be taught how to draw and experience success in drawing, especially in relation to the transferring of mental images into physical representations. They should be taught how to articulate their ideas and defend their thinking in an encouraging yet critical environment.

Exposure to a wide range of experiences is crucial. This can be done in several ways: getting students out of the classroom and interacting with design in the real world, taking them to exhibitions, inviting designers into classrooms and running workshops with students, and tapping into authentic stakeholder feedback. If students design based on tacit knowledge and experience it stands to reason that design education should broaden their understandings. Design briefs should be varied, challenging and delve into real issues such as environmental sustainability. Students should be able to see the relevance of what they are learning. Projects should allow for the explicit use of student passion and interests. By doing this students already have buy in and the ability to use some tacit knowledge (Cross 2003; Schon 1983).

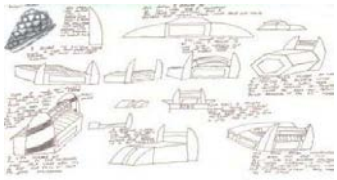
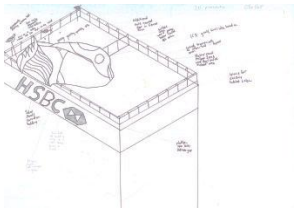
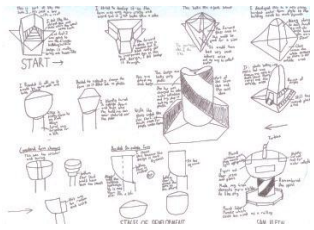
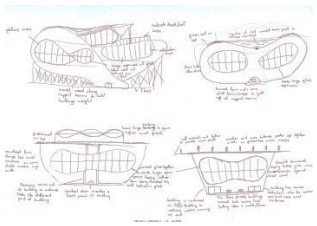
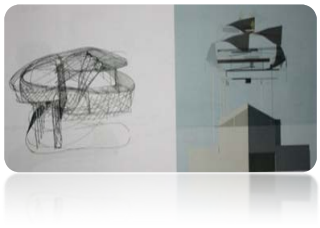
Students need to be taught to truly perceive; to notice and question the world around them and use this when designing. Teaching traditional drawing can be a good way of doing this as it forces students to slow down and really look at things. Without unlocking the fear of drawing students are limited in their ability to record and fully develop ideas (Cross 2001a). Students should feel confident in their drawing and have their eyes opened before attempting to solve design problems.

It is alarming to think that some students may enrol into courses without an accurate picture of what that course entails and that some talented students may not be accepted into courses because their portfolio does not contain the thinking universities are looking for. If secondary school educators were more aware of what tertiary institutes were looking for in their undergraduates, they could better prepare students wishing to pursue design. Conversely, if tertiary educators were aware of the kind of projects being delivered, and the level of design thinking happening at secondary level, they would have a better understanding of students' strengths and weaknesses. This kind of productive communication could lead to the extension of design expertise in general and actively assist in the development of student to practitioner.

Personal experiences of education appear to be something that we keep with us always, so it makes sense to ensure educators are doing their utmost to make such experiences rewarding and positive. Our hope is that this study may generate professional dialogue and inspire changes to pedagogical practice enabling design

educators to grow great designers and aid them in keeping their students' colours bright. At the very least it should make educators reflect on how we assist students in solving design problems.

Table 1. *Design samples across Broadbent's categories of form generation.*

Student	Design sample	P	I	A	C	Explanatory notes
S		3	-	1	1	Functionality has commanded most design decisions. Form derived directly from tropic shell. Interior space has been sectioned using strict symmetry.
S		2	-	3	-	Form derived from concept of bio mimicry (fungi). Functionality takes a slight back seat to concept of form but still dominant in development.
S		3	1	-	1	Initial form derived from participants understanding of a house shape and then developed with rigorous attention to functionality. Interior space and overall uses mathematical systems.
S		1	-	3	1	Initial form derived from shape of a surfboard. Form has guided and helped to develop the integration of functional aspects. Interior spaces have been laid out using mathematical systems.
T		-	-	3	2	Form derived from Mobius loop (a mathematical concept). This concept drove development

T		1	1	3	-	Form inspired by Pakistan winder catchers and concept of traditional, low tech sustainability. Functional aspects apparent but not fully as important or fully resolved.
T		-	1	1	3	Form and concept derived from New Zealand villa. Concept was to modernise a cultural icon, done in part by mathematic systems in regard to the treatment of space.
T		-	-	2	3	Form derived from and development guided by the mechanisms of a clock. Mathematic rules used when dealing with mechanism analogy.

S= secondary samples, T = tertiary samples.
P= pragmatic, I= iconic, A= analogic, C= canonic.

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References

Atman, Cynthia J., Chimka, Justin R., Bursic, Karen M., and Heather L. Nachtmann. 1999. "A comparison of freshman and senior engineering design processes". *Design Studies* 20: 131-152.

Broadbent, Geoffery. 1973. *Design in architecture: architecture and the human sciences*. London, New York, Sydney, Toronto: John Wiley & Sons.

Cross, Nigel. 1990. "The nature and nurture of design ability". *Design Studies* 11(3): 127-140.

Cross, Nigel. 1997. "Descriptive models of creative design: application to an example". *Design Studies* 18(4): 427-440.

Cross, Nigel. 2001a. "Design cognition: results from protocol and other empirical studies of design activity". In *Design knowing and learning: cognition in design education*, edited by C. M. Eastman, W. M. McCracken, & W. C. Newstetter. Elsevier.

Cross, Nigel. 2001b. "Designerly ways of knowing: design discipline versus design science". *Design Issues* 17(3): 49-55.

Cross, Nigel. 2003. "The expertise of exceptional designers". In *Expertise in design*, edited by N. Cross & E. Edmonds. Sydney: Creativity and Cogntion Press.

Cross, Nigel. 2004. "Expertise in design: an overview". *Design Studies* 25(5): 427-441.

Cross, Nigel., and Anita Clayburn Cross. 1998. "Expertise in engineering design". *Research in Engineering Design* 10(3): 141-149. doi:10.1007/bf01607156

Cross, Nigel, and Kees Dorst. 1998. "Co-evolution of problem and solution spaces in creative design: observations from an empirical study". In *Computational models of creative design* (Vol. 4), edited by J. Gero & M. L. Maher. Sydney, Australia: University of Sydney.

Cross, Nigel, and Kees Dorst. 2001. "Creativity in the design process: co-evolution of problem-solution". *Design Studies* 22: 425-437.

Cross, Nigel, Naughton, John, and David Walker. 1981. "Design method and scientific method". *IPC Business Press* 2: 195-201.

Dorst, Kees, and Isabelle Reyman. 2004. "Levels of expertise in design education". Paper presented at the meeting of the International Engineering and Product Design Education Conference, Delf, The Netherlands.

Dreyfus, Hubert. 2003a. "Can there be a better source of meaning than everyday practices?" Lecture notes from the second 2003 Spinoza Lecture at the University of Amsterdam.

Dreyfus, Hubert. 2003b. "From Socrates to artificial intelligence: the limits of rule-based rationality". Lecture notes from the first 2003 Spinoza Lecture at the University of Amsterdam.

Heidegger, Martin. 1968. *What is called thinking* (J. G. Gray, Trans.). New York: Harper & Row.

Merleau-Ponty, Maurice. 1962. *Phenomenology of perception* (C. Smith, Trans.). London: Routledge. (1945).

Rittel, H. 1972. "On the planning crisis: systems analysis of the first and second generation". *Bedrift Sokonomen* 8: 309-396.

Roberts, Philip. 1982. "What is design?" *Journal of Art and Design* 1(2): 269-278.

Schön, Donald. (1983). *The reflective practitioner*. London: Temple-Smith.

Simon, Herbert, A. 1969. *The sciences of the artificial* (3rd ed.). Cambridge, Massachusetts: MIT Press.

Spendlove, David. 2007a. "Still thinking and feeling: the location of emotion in the creative learning experience". *Design and Technology Education* 13(1): 11-18.

Spendlove, David. 2007b. "We feel therefore we learn: the location of emotion in the creative and learning experience" (Part 1). *Design and Technology Education* 12(3): 7-16.

Wells, Alistair. 2010. "It happens anyway? The place of creativity & design thinking in technology education". Paper presented at the meeting of the Technology Learning and Thinking: Culture, Design, Sustainability, Human ingenuity, Vancouver, British Columbia.