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Abstract
In 2005, Coventry University was successful in bidding for Centre of Excellence in Teaching and Learning (CETL) funding from HEFCE, which led to the creation of the Centre of Excellence for Product and Automotive Design (CEPAD).

This article discusses pedagogic research carried out by CEPAD to date, with a particular focus on the journey towards identifying one particular threshold concept in student transport and product design education. It also explores preliminary thoughts on how this identification of hitherto tacit knowledge can feed into the design thinking and solutioning process. From this, the article offers some implications for the enhancement of teaching and learning within the design curriculum.

Keywords
design curriculum threshold concepts industrial design tacit knowledge CETL
Pedagogic research

Introduction
In 2005, Coventry University was successful in bidding for CETL funding from HEFCE, which led to the creation of the Centre of Excellence for Product and Automotive Design (CEPAD). At its inception, CEPAD developed a qualitative research framework underpinned by a longitudinal study of a cohort of transport and product design students from entry to graduation. The aim was to investigate the development of transport and product design students' spatial awareness skills, enable the identification of thresh- old concepts in design, and enhance connection with the global community of designers through the internationalization of the design curriculum.

This article focuses on one particular strand of the CEPAD research framework – the journey towards the identification of a threshold concept in design – and examines how the identified threshold concept sits within the process of design thinking and solutioning. The article also considers some implications of this for the enhancement of teaching and learning in the transport and product design curriculum.

Identifying the threshold concept
The threshold concept research framework was first introduced by Meyer and Land in 2003, who describe a threshold concept as:

> *... akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress.*
>
> (Meyer and Land 2003: 1)

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In more detail, threshold concepts have several, distinct, characteristics in that a threshold concept can be considered *transformative* – once a student has grasped a threshold concept, it involves a personal as well as a conceptual change; *irreversible* – once understood the student is unlikely to forget it; *integrative* – opens up the connections between the things the students have been learning and thus enables new possibilities to emerge from this under- standing, and *troublesome* – likely to involve forms of troublesome knowledge which 'appears counter-intuitive, alien ... or seemingly incoherent' (Perkins 1999 in Meyer and Land 2003: 7). Also important in terms of thresh- old concepts is the term 'liminal space': whilst students are trying to grasp a threshold concept, they experience a sense of uncomfortable intermediacy, while they struggle for understanding, and this struggle can involve identity shifts and 'troublesome, unsafe journeys' (Cousin 2006: 5).

It was therefore hoped that the framework would offer a 'way in' to the type of course that is not entirely bounded by learning outcomes – in other words, a creative course which tends to work with what Davies describes as 'ambiguous terms such as "creativity", "imagination", "originality"' (Davies 2003: 2). As such then, within this type of course, the focus may be on the critique of a 'collection' of student work in order to understand where learning outcomes have been met, rather than producing individual pieces of work to meet each learning outcome – a task which can be both overwhelming and burdensome for students in wide ranging subjects such as design. Thus, the threshold concept framework had the potential to apply 'a lens' to illuminate the transformative moments that students experience on a course which focuses on creativity, emphasizes individual agency and is also underpinned with tacit knowledge, described by a design tutor, as an 'underlying agenda of things we know the students need to have'.

The research into identifying threshold concepts in design began with a consideration of whether spatial awareness development was a threshold concept for students, as this is seen by staff as a crucial component for students who wish to successfully enter the professional design community of practice. As such spatial awareness skills are looked for in application portfolios and count greatly towards entry onto the Transport and Product Design courses.
Using the research question 'Is spatial awareness development a thresh- old concept for first year students on the transport and product design course?', students who volunteered for the longitudinal study and their tutors were interviewed to establish a definition of spatial awareness as it related to the course. A significant finding was that there was no 'one' definition of spatial awareness, and as reported in Osmond and Turner (2008), staff responses included 'all round awareness' to 'design sensitivity', whilst student responses were categorized as 'having no knowledge', 'little knowledge' and 'guessing'.

Meanwhile, a concomitant research aim was to develop a spatial awareness measurement tool and this was implemented with 114 first year students alongside an existing tool – the 'Purdue Visualization of Rotations Test' (Bodner and Guay 1997). The results of both tests were analysed[11], and then compared with the students' end of year assessment results, but no

[1] Statistical analysis of the results was con- ducted using SPSSTM statistical software (version 14.0). Data were checked for normality before the calculation of mean scores. Correlations were carried out using Pearson and Spearman Rank tests as appropriate
(Ho 2006).

correlation was found. In other words, the students' spatial awareness development bore no relation to their ability to successfully complete the first year of study. The research team concluded that spatial awareness development was not a threshold concept for the first year of study; further it was concluded that spatial awareness as it is convention- ally understood in the literature is not closely aligned to the form-based creativity associated with industrial design practice. From this came a shift in focus towards notions of visual creativity, and research in this area is currently ongoing.

However, a potential threshold concept did emerge from data: initially called 'the confidence to challenge', this potential concept was further investigated with staff and students during year three of the project. The 'confidence to challenge' is defined by staff as the ability to '... inculcate design conventions and expand upon them using information from a variety of sources and experiences'. Without this confidence students may get 'stuck' in Meyer and Land's 'liminal space', constantly 'surfacing around' in search of inspiration as they tackle what Buchanan calls 'wicked problems' (Buchanan 1992: 6).

As reported in Osmond and Turner (2008), evidence to support this threshold concept was found in the qualitative data produced from the student interviews in that several students reported a feeling of 'being stuck' when faced with a design brief, perhaps epitomized by this comment from a first year student:

> *I think during the very beginning I really struggled to really know what I should do in my projects – you really spend a lot of time to think about it but the result is not really that good as you expected because you keep surfacing around, you can't really make decisions about doing ... that's one of the most negative feelings because you don't know what to do sometimes – I mean I understand you do projects it is not really satisfying teachers, you learn during the process, but still you want to know what they really want.*

In one particular case, another first year student entered the second year of the course without losing this feeling, and commented:

> *If it is someone else's drawings you can bring it to life and it is a lot easier. I didn't struggle so much with the first assessment – the second assessment was more you had to design something and that is when I struggled ... even though it is a design course.*

Although this student successfully completed his second year, he subsequently left the course commenting that 'I have learnt that I don't want to be a designer and I no longer have the passion to be one' – indicating that he was, in the end, unable to trust in his creative abilities. In contrast, another first year student who displayed a lack of confidence in his designs in the first year, was able to successfully defend a design in the second, evidencing an increase in confidence in terms of coping with the uncertainty of the design process.

There are also some indications that some students do not pass through this threshold concept until later in the course, as evidenced by the experience of a final year student who, up until this point, had produced perfectly competent designs, but, after a period of intense uncertainty produced an innovative, original design for the final year degree show:

> *Normally when I design something I have a sort of vision in my head of what it is going to be and what the finished thing is going to be and usually it only takes a couple of goes to get it right and then I have to bulk out the rest of it with ideas that I made up afterwards. But this time I literally – my mind exploded – I can do anything, literally do whatever I want and I couldn't stop – I couldn't stop designing – everything I designed I was like well that's not right so I went onto a completely different one as opposed to amending the one I had already done ... [but] suddenly it was like ping! I just got an idea, I did it, we made it and ever since then I have been developing it slightly and nothing much has changed and it has all come together really well.*

The notion of 'surfacing around' or a period of uncertainty during the design process is well documented in both the design literature (see Cross 1992; Dorst 2003) and in the creativity literature (see Kleiman 2008; De-Bono 1995). It is perhaps best epitomized by this quote from Tovey:

> *It is possible that the incubation periods, that time of apparent inactivity during which the designer's brain furiously grapples with the problem, is simply the period during which the two halves of the brain are out of touch or unable to agree. But contrast the moment when they do suddenly come into alignment would be the classic 'eureka' point.*
>
> (1984: 226)

It seems that incubation period relates to Meyer and Land's 'liminal' state, and as such is part of the design process: once students recognize this as such, they have then gained the confidence to challenge design conventions and then produce innovative designs. From this, the research team concluded that it was the process *leading up to* the confidence to challenge that is the threshold concept and it has tentatively been called 'the toleration of design uncertainty'.

Discussion

Typically then, design problems are ill-defined, ill-structured, or 'wicked'. When designers embark on a piece of design they do not have all the information that is necessary to solve the design problem. In fact it is argued that they almost always lack a proportion of it, and that by their nature design problems are not susceptible to exhaustive analysis. Experience indicates that ideally the only practicable way forward is to produce a draft solution, so that the problem can be kept within manage- able bounds.

This approach seems to be core to designing and implies a whole way of understanding the world and responding to it. This has been characterized as the 'Designerly Way of Knowing' by Cross (1982), a mode of thought that has five aspects:

1. Designers tackle ill-defined problems
2. Their mode of problem solving is solution focused
3. Their mode of thinking is constructive
4. They use codes that translate abstract requirements into concrete objects
5. They use these codes to both read and write in the object languages

However, for students there is a very particular transitional stage that they need to pass through in order to feel confident enough to quickly produce a draft solution. As this article has outlined, it is possible that the uncomfortable and troublesome 'explosion in the head' needs to not only

take place, but be accepted by students as a routine – but nonetheless exciting – part of the process of producing draft solutions. That this stage is well documented in the literature indicates that professional designers recognize this experience, but up until this point this knowledge seems to have been tacit in relation to student design education. As a result, discussion is also ongoing on how to best develop support frameworks to help understand how curriculum development can be influenced by the identification of the threshold concept; with the intention of introducing learning objectives into modules that specifically address and legitimize the students' experience of uncertainty in solving design problems.

In addition, the development of a model that calls upon knowledge of the critical points of the design process is in discussion and this model would site the toleration of design uncertainty in the pre-concept design stage where exploration of the 'design problem' takes place. This will be outlined in future articles.

Conclusion

From the CEPAD research into identifying threshold concepts in design, it has become evident that within visual intelligence and the development of designerly approaches, spatial awareness itself is not a threshold concept. However, CEPAD has found that the 'toleration of design uncertainty' within the design process is a major threshold concept within student design education, which has hitherto gained only tacit recognition within the curriculum. This finding is to be used to inform future curriculum development in design as learning to deal with ill-defined problems is at the core of design thinking. The CEPAD team now aims to investigate ways that students can be supported in gaining confidence to deal with 'unknown' or 'difficult' design situations, which range from the solving of a functional design problem to the decision-making associated with the resolution of a complex form. Finally a model is in development, which sites the toleration of design uncertainty in the pre-concept design stage.

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