MODELING PARADOXES IN NOVICE AND EXPERT DESIGN

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ABSTRACT
In their ICED09 paper 'Problem formulation as a discursive activity', the authors have used an extensive educational case study to explore a framework for describing design as a discursive activity, centered around the paradoxical nature of the problem situation. The 'working definition' for paradox that was used as the basis of that paper will now be re-examined, extended and detailed in the light of studies on expert designers. In particular, paradoxes will now be situated as an opposition between frames or within frames. Expert designers can be seen to build up a rich picture of the frames at play in a design situation, and extract themes that can lead to reformulation of the problem as well as the creation of innovative solutions. This behaviour is compared to the ways of working of novice designers (students) in the original case study.

Keywords: paradoxes, design expertise, frames, themes, design education

1 INTRODUCTION
In the ICED09 paper 'Problem formulation as a discursive activity', the authors have used an extensive educational case study to develop a framework that describes design as a discursive activity (based on the notions of 'discourse' and 'paradox') for the close description of problem formulation in design. The 'working definition' for paradox that was used as the basis of that paper will now be re-examined, extended and detailed in the light of an observational study of expert designers. The new descriptive framework will then be re-applied to the original case study.

2 PARADOXES AND DISCOURSES
A key element of design thinking is the way it deals with paradoxes. In her book 'Ethics in Engineering Practice and Research' Caroline Whitbeck remarks that

> "... The initial assumption (*within moral philosophy)* that a conflict is irresolvable is misguided, because it defeats any attempt to do what design engineers often do so well, namely, to satisfy potentially conflicting considerations simultaneously" ([1], p. 56).

A 'paradox' is seen as a complex statement that consists of two or more conflicting statements. All the statements that make up the paradox are true or valid in their own right, but they cannot be combined. A paradox thus requires a redefinition of the problematic situation in order to move forward to a solution. In the ICED09 paper, we proposed that the elementary statements that make up the paradox, and the viewpoints and ways of thinking that underlie these statements can be described in terms of 'discourses' [2]. The term 'discourse' was borrowed from Foucault and used to describe the complete structure of terms and relationships that lie at the basis of the thinking and discussions within an area of human activity. As the terms and relationships within a discourse are the elements of human thought, the discourse in a field spans the *complete* breadth of human thinking within that domain. In most design disciplines, there are many discourses which have to be linked in the creation of a design solution. In product design practice, relevant discourses include the bodies of thought about technology, form and aesthetics, ergonomics, marketing, etc [3]. We stated that specific discourses can be directly embodied by the different stakeholders involved in the project (e.g. a manufacturing company 'representing' technology). In the ICED09 paper, we proposed that a level-1 paradox occurs when different discourses cannot easily be resolved within the design solution. For example (taken from the extensive case study for the design of a city market in Copenhagen, see 4.1), a market stall based on a tent like structure might be a good solution for the sales persons, but what about fire safety?

The fire brigade's ideal solution is an open field, but that is not a meaningful solution to the design problem of creating a mid-city market. In these paradoxical design situations *trade-off* thinking is crucial. This direct clash of external criteria we have called a level 1 paradox.
More complex paradoxes can be sparked when many different discourses have to be synthesized into a design solution. These 'level 2 paradoxes' can be sparked by external stakeholders, but they often also occur within design teams: different designers are likely to bring a wider array of discourses to the table, or present varied subjective preferences within the common discourses. Design teams have to reconcile these fundamental differences by creating a modicum of shared understanding in order to move forward at all. In the ICED09 paper, we concluded that as design researchers and design educators, we have to make sure that we articulate this 'tuning' process explicitly, and point it out as a separate concern – perhaps even a separate stage within the design process. The skills required for adequate tuning range from direct action-skills like communicating and negotiating to meta-level skills of empathy and diplomacy to support the design team discussions. As tuning is such a crucial process for the effective functioning of a design team, these often overlooked skills should be receiving adequate attention in design education.

3 PARADOXES RELOADED

There are two ways in which we would like to extend this exploratory line of research on design paradoxes in this paper:

1. The research presented above was performed in an educational context, and focuses on the behaviour of Novice designers, namely 1st year design students (see [4] and section 3.1 for a brief explanation). The array of strategies that these inexperienced designers can bring to a design situation will be limited. For a more general understanding of the nature of paradoxes in design, we need to augment the study by including observations on professional designers.
2. Within the ICED09 theoretical framework, the origin of paradoxes is placed in the clash of the discourses of different stakeholders. While that may have been the relevant kind of paradox-clash for the educational empirical study, we need to be wary of oversimplifying the situation and/or over-generalising the findings. In this paper we are looking in detail at the way expert designers work. This allows us to observe that in their design practice, the clash at the core of the paradox is actually between frames rather than discourses. We will explore the way expert designers deal with these frame clashes, and seek to get a better understanding of how designers move away from the original paradox.

Through these explorations we hope to develop a better set of concepts to describe and understand the ways both students and expert designers deal with paradoxes in design.

3.1 Experts and Paradoxes

Before we describe the behaviour of expert designers in, we need to contextualise the notion of expertise by briefly reiterating a general model of design expertise [4], that was based on general models of expertise and expertise development in other professions [5]. For the purpose of this paper, it will suffice to distinguishing 5 levels of expertise.
The **Novice** (1) state involves the exploration of what design is, finding the 'rules of the game'. The key characteristic of an **Advanced Beginner** (2) is the recognition that design problems are highly individual and situated. Design problems at this level are considered to be less amenable to the use of standard solutions (the 'rules of the game') than they were at the novice level. The **Competent** designer (3) is one who can handle and understand all the normal kinds of situations which occur within the design domain. In process terms a competent designer becomes the co-creator of the design situation, through strategic thinking. This enables the designer to be much more in control, not only over his/her own project but also by steering the development of the design problem. The **Expert** designer (4) ('expert' as in 'better', not as in 'specialized') may be characterized by a more or less automatic recognition of situations and a quick, intuitive and dead-sure response. The **Master** designer (5) has taken his/her way of working to a level that question the established way of working of the field, as represented by the practices of the experts.
Thus the development of the design approaches that accompanies the general expertise development runs from 'rule-based' (or: convention based) to 'situation-based', to 'strategy-based', and then on to 'experience-based' and to the 'development of new schemata and frames'.

The core paradox in the expert protocol study [3], in which 12 professional designers were asked to (individually) design a 'litter system' for in a train, was the contradiction between the requirements of passengers and cleaners for the litter system. An ideal design for the passengers would basically involve a lot of litter collection points spread around the carriage, easily reachable from a sitting position. The ideal for the cleaners is one central bin that can be emptied quickly and efficiently, without having to reach into awkward spaces between seats or bending over. That is the level-1 paradox as given to the designers in the project brief.

The expert designers confronted with this level-1 paradox displayed different overall strategies; some tried to find a way around the paradox by widening the system barrier, looking at the train or the railway carriage as a whole, coming up with original solutions that make use of the possible spread of functionalities through the different parts of the train. Some experienced designers followed a strategy in which they made separate designs from the standpoint of the main stakeholders (i.e. a couple of sketches exploring what would be good for the user, and some sketches in which they championed the cleaners), and then they tried to integrate some of these solutions into an overall design. These expert strategies are in stark contrast to novice designers (2^{nd} year design students) that were confronted with the same design problem: they stuck closely to the problem as presented, and followed 'rule-based' and 'situation-based' approaches that led them quite inadvertently to create compromise solutions in the immediate environment of the passenger. Their view of the problem was comparatively shallow, and effectively limited to a level-1 paradox. Most importantly: in doing so they followed the design approach that was used as a basis for our description of the interaction between paradoxes and discourses in the ICED09 paper.

3.2 Paradoxes, frames and themes

Since the writing of that paper, we have realised that the description of a paradox as a clash between discourses (where discourses are often linked one-to-one to stakeholders) is an oversimplification. This descriptive framework may suffice for covering the ways of working of novice designers, but it doesn't help us in describing the much more subtle ways these expert designers dealt with paradoxes.

We can observe that expert designers get beyond the global level-1 paradoxes (that could be characterised as a clash of discourses) and explicitly analyse the paradoxical design situation in terms of complex frames. Frames are seen as applied (situated and specific) views on the problematic situation derived from the general discourses. This distinction between discourses and frames is important, because it is exactly the sensitivity to the situatedness of frames that allows expert designers to question the existing (given) paradoxical problem situation. Expert designers understand that the problem situation has already been framed in a certain way by the stakeholders, deliberately or quite inadvertently, through the very act of expressing it. They seek to create original solutions through questioning the initial problem-as-presented, and reframing it when they can. Novices tend not to question the original paradox or the way it is expressed very thoroughly. In design education, we tend to encourage students to be looking for 'the problem behind the problem', but that mostly comes down to creating a needs-analysis of the key stakeholders. And, on reflection, this wording could plant the mistaken belief that there IS a single problem hidden behind the problem-as-given, that could be uncovered through a search process. This is a far cry from the expert's critical engagement with the frames of the stakeholders.

This is where we have to step back and realise that although frames (in the definition of a specific viewpoint, a 'seeing- as' that has the potential to lead to the creation of solutions) can sometimes be paraphrased by a simple and elegant statement (often metaphorical), they are actually quite complex and subtle thought-tools. Furthermore, they can be implicit, vague, and they can contain internal contradictions that need to be sorted out when applying them. In the protocol study [3] of the design of a 'litter system' for in a train, expert designers picked up that 'the passengers' don't have a simple or coherent discourse at all – assigning a single discourse to them would be a gross oversimplification. Even if we set aside the wide variety of passengers in the trains (at different times of the day), that are all bound to have their own views on what would be a good public transport experience, talking about the passenger's frame is highly problematic. Within any passenger's frame, themes like the need for hygiene (e.g. smell!), ease of use, their sensitivity for reuse (sustainability) and their broader social

awareness of fellow passengers all vie for attention. These needs could easily lead to contradictory requirements for the design.
The expert design solutions that were judged best by a panel of independent assessors were the ones that addressed a number of these underlying themes in a simple, integrated solution. The solution that came out as the best consisted of a number of smaller bins among the chairs, and a big 'newspaper rack' close to the doors at the end of the railway carriage. In this scenario, somebody reading a newspaper would not stuff it in the rubbish bin after reading, (resulting in them filling up quickly, and needing to be emptied) but could leave the newspaper for others to read – pushing it behind the bars of the newspaper rack at the end of the carriage as they were leaving the train. So the intimate engagement with the frame of the passenger in all its complexity has led to a design solution that much more subtly address the level-1 paradox in the design situation: the passengers wanting to get rid of their rubbish without reaching too far or standing up, versus the cleaners needing to work efficiently.

Thus we see that the discerned 'themes' that could be judged peripheral to the central problem can become the triggers for the creation of new frames that help the designer resolve the core paradox. The fruitful frame that this expert designer created focused on the theme of distinguishing between 'trash' and 'newspapers'. Expert designer all realised that this distinction is felt by the passengers in their lived experience, and that working with this theme could lead to promising solutions. In their design processes the broader set of themes at play in the problem situation (such as the passengers feeling for hygiene, ease of use, sensitivity for reuse and social awareness) worked as a trigger, directing the creative imagination in the direction of such new frames. The expert designer's ability to understand the core level-1 paradox between frames in a design situation in the context of a broader set of themes allows them to create and propose a new frame for the situation. This frame then carries the potential to the creation of truly novel solutions.

What the expert designers are engaging in here is a subtle process of analysis that is very close to the methods used in phenomenology: they analyse the situation by discerning the 'themes' that underlie the frames of the stakeholders. The term 'theme' as we use it here is a complex theoretical notion, adopted from the methodology that is associated with hermeneutic phenomenology [6, p 89] – where the notion of themes is used as a stepping stone for creating well founded descriptions of 'lived experience'. In phenomenology a theme is the experience of focus, of meaning, of point. Its formulation is at best a simplification but often more a labeling of a set of significant experiences - not directly linked to one specific observation, but they are seen to underlie many observations. They are in a sense a tool, a form of capturing the underlying phenomenon one tries to understand. Themes come about from the needfulness or desire to make sense – they ARE the sense we are able to make of something when we approach it openly. Distilling themes from a complex situation is described as a process of insightful invention, discovery and disclosure. As an example, Van Manen [7] writes that professionals have to understand the themes that underlie the lived experience of their clients in order to help or support them. The term lived experience highlights the fact that the client's experience of and life with his/her problem can be very different from the professional's understanding.

"*How do we experience our body in illness or health? … Increasingly the health science professional is becoming aware that people require not only health care assistance, surgical treatment, or pharmaceutical treatment, but that the professional be much more involved in the way that people experience and live with their problems in a different, sometimes deeply personal and unique manner.*"

This is also true for designers, where an initial understanding of a stakeholder's frame can be an oversimplification. Miller [8] described a product development project in the Danish company Novo Nordisk where a user-oriented approach was applied for the design of diabetics equipment. It was decided to make video observations of diabetics to understand their daily lives, and a student travelled to several countries around the world to make videos of diabetics. The video protocols were studied by the product development team and it was a huge surprise to the engineering designers to see a diabetic injecting himself while he was driving his car. Thus, a new and unexpected theme challenged the engineering designers' original understanding of 'fear of needles' as being the most important design paradox to be solved. 'Injection of insulin while doing other daily routine activities' became a theme, and the company invested in exploring a more varied understanding of the diabetics' daily life with their illness, mapping the lived experience of diabetics. The underlying theme that informed the goal

of the company, in this and subsequent design projects, was transformed to supporting diabetics in their daily lives.

4 RETURN TO THE EDUCATIONAL CASE STUDY

Now it is time to explore how this extension of the descriptive framework (the introduction of frames and themes) sits with the educational case study that was the basis for the ICED09 paper, and what we can learn about the difference between novice and expert design.

The educational case study is based on a design project task: "What if the fruit outdoor-market in centre of Copenhagen was to be improved? Can you design more attractive market spaces?" The students are first semester undergraduates of the Design & Innovation study program at the Technical University of Denmark. Thus, they can be seen as Novice designers, or maybe Advanced Beginners. The design project task challenges each student design team to identify core needs and formulate a design problem. In order to do so each student design team carries through a research phase collecting information based on a socio-technical approach ([9], [10]), where the design team identify relevant actors and collects information from the actors. For human actors, e.g. public authorities, sales person and customers at the fruit outdoor-market, the information collection is done by observation by actors in action and interviews. For non-human actors, e.g. legislative requirements with respect to fire safety, hygiene when selling food commodities and general workplace regulations, the information collection is done by analysis of written documentation. Also, information about existing socio-technical solutions is collected. Based on the collected information and the insight obtained each student design team has to formulate a project goal and write a design specification document. Upon conclusion of the research phase the student design teams begin their synthesis activities. Firstly, during a concept design phase at least three concept proposals have to be created. Thereafter, the design team selects a concept proposal for embodiment and preliminary detailing. By the end of the design project the design team has to hand in a poster describing their design problem and the synthesized solution and a scale model of the solution.
The design project task on the fruit outdoor-market is used every second year, and our educational case study is based on the design specification documents of the 10 student design teams from the 2006 cohort. We have studied the design specification documents to identify actors, issues, requirements and goal statements as comprehended by the student design teams. Then we have summed up actors, issues, requirements and goal statements, which have been mentioned by several design teams. We have also studied scale models of the solutions synthesized by the student design team in years 2004 and 2006, in order to understand how student design teams have tackled their design problem, i.e. how they handled clashing of frames. Thus, the empirical material gives us an opportunity not only to examine our sharper 'working definition' of a design paradox, but also to reflect upon the student design teams' consecutive design behaviours.

4.1 The design problem described as a paradox

We will describe the case of a specific group as a narrative. Let us focus on a student design team working on the problem of creating "A good market place for the sales persons and a market place which attracts many customers". Their initial ideas regarding the solution are: "a tent like design" which is easily erected and dismantled, "something disappearing in the ground at night" to avoid transportation to and from a night storage, and "a lightweight market stall" because the erection and dismantling of the existing stalls is heavy for the sales persons and noisy for the neighbours. To unfold the design problem the student design team splits up in 3 sub-groups in order to collect information from many sources.
The first sub-group is concerned with legislative requirements and focuses on the fire brigade and the food administration as important actors. The group members have a meeting with the fire brigade and they identify the fire brigade's frame as "fire safety", and in relation to this frame "access for fire engines" and "free escape routes" are themes. A meeting with a food administration officer results in the identification of the food administration's frame as "food hygiene level", and within this frame themes are "avoid contamination of food commodities", "daily cleaning of market stalls" and "easy to control food hygiene". Thus, the first sub-group is facing a clash of three frames, viz. frames of the sales persons, the fire brigade and food administration. The initial idea of a market stall based on tent

like structure might be a good solution for the sales persons, but many lightweight nylon tents on a crowded marketplace are hugely problematic with respect to fire safety: How to get fast access for fire engines? And are escape routes open and can the customers on the market find the escape routes in the case of a panicked, messy evacuation? With respect to the food administration's legal requirements regarding a satisfactory food hygiene level the sub-group sees the access to water as being very important in order to keep the market stall clean. However, the municipal authorities do not accept permanent installation of water to the market place.
The second sub-group sees the potential in the idea of a tent structure, because this structure is seen as easy to erect in the morning and take down in the evening, which is convenient for the sales persons. However, they have a concern regarding Danish weather conditions, i.e. is it possible to design a tent structure, which is robust against heavy rain and wind. The ideas or proposals that the sub-group can think of to improve the structure's robustness seems to result in a heavier structure, which is more difficult to handle morning and evening.
The third sub-group contacts the lord mayor's office for an interview and the group realizes that in order to obtain political support towards new market stalls the politicians' frame is "being recognized as visionary political leaders of Copenhagen". The group members discuss their interview in detail and interpret it into two themes "a landmark of Copenhagen" and "an integrated part of the Copenhagen townscape", and the group members agree on the goal to develop "a new and radical innovation, which challenges the concept of outdoor market spaces".
In this paradoxical design situation we see three sub-groups each having ownership of certain frames from different actors: the food administration, the municipal authorities, the sales persons, the Danish weather (a non-human actor which has to be taken into account), the local politicians, etc. and the frames are populated with themes like: "access for fire engines" and "free escape routes" etc. Also, each sub-group has some ideas and proposals, but it is not easy to imagine solutions which transcend the frames. Now, let us see what happens when the three sub-groups meet and try to create a design problem and proposals for solution: Any member of any sub-group who proposes an idea or a solution principle to the design team will be met by reservations, e.g. "but water is not allowed in permanent installations", "a tent structure is not very innovative", or "too many shelves means much time for cleaning – and we have no easy access to water." The design team finds itself in a complex, paradoxical design situation where many frames are clashing. This results in design team paralysis.

4.2 Design behaviour of student design teams

In order to reflect on the design behaviour of the student design teams, we will use the scale models of solutions handed in by four teams, see figure 1. The four solutions are alternative solution proposals to the design problem. However, we have to be careful in judging these: firstly, the medium of scale models does not allow a clear evaluation with respect to the food administration's frame. Secondly, although customers obviously are very important at a market as stated in the problem formulation "… a good market place, which attracts many customers" we will not engage with the evaluation of the solutions seen in the customers perspective, because it is unclear from the models how and whether the students have engaged with this.

(a) Proposal no. 1

(b) Proposal no. 2

(c) Proposal no. 3

(d) Proposal no. 4

Figure 1. Four alternative solution proposals

Proposal no. 1 attempts to create a genuinely innovative shape for the market stall – but there is no counter, and placement of fruit close to the ground is not attractive for the sales person (bending over again and again). Then again the mechanism for opening and closing is nice and silent, which is good for sales persons and neighbours. If the pole is permanent fixed in the ground it is possible to make a layout of the market place satisfying the fire brigade's themes. However, then the stalls cannot be removed at night, and this will make it difficult to have events like concerts at the square in the evening.

Proposal no.2: is a genuine market stall seen from the sales person's frame. It is close to a conventional stall. The trolley makes it comfortable to transport fruit to the stall. It is not an innovative shape – not much landmark and innovation here. Opening in the morning and closing and removal in the evening is as noisy as with the existing stalls. Also, setting up every morning will make it difficult to design and enforce "free escape routes".

Proposal no. 3 explores the possibility of creating clusters of stalls. If the poles are permanent fixed in the ground it is possible to make a layout of the market place satisfying the fire brigade's themes. However, then the stalls cannot be removed at night, and this will make it difficult for events to take place in the evening.

Proposal no. 4 is a hybrid, "a tent on wheels". Is especially attractive seen in the municipal authorities' frame. Water and a tank to collect waste water can be installed, and the square will be available for other events in the evening. However, with respect to all the other frames it is not very good. Table 1 summarizes these observations.

Table 1. Evaluation of solutions proposal with respect to the 'model' design problem

Frames and *themes*	Proposal no. 1	Proposal no. 2	Proposal no.3	Proposal no. 4
Sales persons: "a good market place, which attracts many customers"				
"good display of fruit"	+	+	+	+
"convenient working conditions"	-	+	+	-
Politicians "being recognized as visionary leaders"				
"a landmark for Copenhagen"	+	-	+	-
"an integrated part of the Copenhagen townscape"	+	+	+	-
Fire Brigade: "fire safety"				
"access for fire engines"	+	-	?	-
"free escape routes"	+	-	?	-
Municipal authorities: "satisfy local regulations"				
"no permanent installation of water"	-	-	-	+
"use the square in the evenings for other events"	-	+	-	+
Neighbour: "the fruit market shall be a pleasant neighbour"				
"*not too noisy erection and dismantling*"	+	-	?	+

What we can observe is that the student design teams are thinking to-and-fro between the frames of the different stakeholders. For example, proposal no.1 satisfy the politicians' and the fire brigade's frames, but to the cost of the municipal authorities' frame. Proposal no. 4 is good with respect to morning and evening activities (opening and closing) but it will be difficult to design and enforce "free escape routes". The students' formulations of design specifications are one-dimensional and quite categorical (closely connected to their own, often rule-based way of thinking). It seems that the statements of the various stakeholders become absolute commandments for the teams, effectively reducing the solution space to zero. The teams fail to get behind the frames as they are stated by the stakeholders, and do not unfold a broader view of the themes that would help create a more fruitful design situation. And perhaps most importantly: they do not engage with the absolutely crucial (but admittedly underrepresented) stakeholder, the market-goers (in all their variety), at all. By failing to do so they are cut off from the richest source of themes that would enable them to reframe the situation and create great value in new and unexpected ways… While we do not have data on expert designers dealing with this same problem (that is further research), one could imagine expert designers focusing on a much better articulation of the market space that subtly divides different types of users (tourists & locals, youngsters & elderly, the people that come on a (quiet) rainy day & the (crowds of) summer visitors) and create an overall market design that services them in subtly different ways.

5. EXPERT DESIGNERS' PARADOX STRATEGIES

It seems that in design situations we should make a distinction between the core level-1 paradox, the opposition of forces that makes the problem hard to solve (that makes the situation problematic in the first place) and other smaller level-2 paradoxes in the problem space and solution space. They need to be distinguished, because they are treated differently by experienced designers. The core paradox is often a direct disconnect within or between frames, where expert designers know that thinking to-and-fro between these opposites (as the students tended to do) is not going to help. Expert designers realise that they need to find a way to reframe or change the context of the core paradox. They immediately look at the broader picture, and display problem-avoidance behaviour, using their experience in finding ways to think around the problem-as-presented.

To do this, they broadly analyse the themes that underlie the frames of the different stakeholders – that allows them to go from the position of a problem as a simple opposition of frames to a much richer picture of the problematic situation, envisioning a landscape of opportunities to create value. This is where the level-2 paradoxes within and between frames come in handy. They provide the basic material to be explored in the theme-exploration. The designers go through a phase of extracting the

themes that underlie the level-2 paradoxes, creating a broader picture on how value can be created in this problem area. Through the analysis of themes and the creative playing with the possible solutions that they may lead to, the overall problem is shifted and solutions are conceived.

Please note that although this process is to a certain extent open-ended, it is very much based in analysis, and part of a deliberate push to create solutions to specific sub-problems. This is a far cry from the 'random' element that is coveted by some creativity–gurus and that is at the basis of non-systematic creativity techniques like brainstorming. In contrast to popular views of designing [11][12][13], expert designers seem to avoid these 'scatter-gun' approaches, and favour the careful exploration of the problem landscape [3].

6 CONCLUSION

In the original student case study, as reported in the 2009 paper, the students tried to deal with paradoxes in their very complicated problem situation in a number of ways: (1) a tuning process, (2) by utilising "constructive conflict" (3) a keen awareness of the assumptions (4) by creating a "third space" outside all of the frames, (5) by creating bridges between the frames, or (6) constructing a compromise. As students are still learning the tricks of the trade, these 'rule-based' and 'situation-based' strategies led to various levels of success. As is often the case with student work, there are kernels of very good ideas in this, but overall the groups didn't reach a very strong resolution of the core paradox. In looking back at these projects now, we can also observe that the students stayed close to the core paradoxes they were given, and didn't build up a rich view of the smaller paradoxes that lurk between the frames in the problem area. Thus they missed many of the themes that could have enriched their solutions. For a more comprehensive description of paradoxes in design we now need to augment this work with studies of Competent, Expert and Master designers.

We see the contribution of this paper as only a first foray into the fascinating study of design paradoxes. The fledgling model of design problems as paradoxes, described in terms of discourses, frames and themes that we presented here needs to be extended and tested through much more elaborate empirical studies on novice and expert designers. The study of how expert designers deal with themes deserves particular attention: these themes potentially perform an important bridging role between the 'problem space' and 'solution space' (in terms of the Rational Problem Solving description of designing) [3]. In terms of the Reflective Practice description of designing, they provide the source material for the creation of new frames. This is particularly exciting, because the question where frames come from has not yet been addressed – neither in Schön's original work, or in subsequent papers that have been written expanding his approach for the field of design.

This research agenda is accompanied by an educational one: design schools should make sure that students encounter many different design situations during their study and that in tackling them they get pushed way beyond just considering the core paradox as it is presented. Students have to be made aware that the quality of the design solutions they are going to create depends on their ability to extract themes from the richness of the frames in a design situation, and to work with these themes in both analytic (rigorous) and creative ways. The richness with which these themes are being picked up could be one of the key characteristics that not just divide the expert designers from the beginners, but also the really good designers from the poorer ones.

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