Design and Other Types of Fixation *or* Is Fixation Always Incompatible with Innovation?

A.T. Purcell and J.S. Gero
Key Centre of Design Computing
Department of Architectural and Design Science
Sydney University, 2006
Australia
{terry,john}@arch.su.edu.au

Abstract

Design educators often comment on the difficulties that result from a premature commitment by students to a solution to a design problem. Similarly practitioners can find it difficult to move away from an idea they have developed or precedents in a field. In the psychology of problem solving this effect is called functional fixedness or fixation. This refers to the observation that people find it very difficult to see, for example, that objects with well known uses or functions can be employed in new or unusual ways to develop an innovative solution to a problem or to solve a problem that requires innovation. Given that fixation refers to situations where innovation is blocked, it is not surprising that these effects should occur in design problem solving. Design problems are essentially ill-defined problems. As such they inherently contain the opportunity for innovation. However, while these types of issues have been discussed in the context of design, there has been little systematic evidence available about whether or not and under what conditions design fixation does occur. The paper reviews the results of a series of recent experiments which begin to addresses these issues. The results of the experiments will then be examined in terms of what insights they provide into the design process and what implications they have for design education and their relevance for the role that computers may play in the design process.

1. Introduction

Through an unusual inversion of everyday ways of thinking, the Gestalt psychologists (Maier, 1931; Wertheimer, 1982) sought to understand innovation and creativity in problem solving by studying problems that most people find it difficult to solve. The basic logic attached to this approach appears to have been as follows. If problems are chosen which require innovative solutions, then studying the conditions under which people fail can give insights into why people find it difficult to produce innovative solutions. One of the central concepts to emerge from this approach was the idea of fixation or functional fixedness. For example, people appear to be unable to see new ways of using objects which could lead to an innovative solution to a problem, because they are blocked or fixated on well learnt uses or properties of the object. A typical problem where fixation is exhibited requires that two spatially separated pieces of string hanging from the ceiling of a room be joined. The pieces of string are not long enough for one to be simply picked up and carried to the other. Present in the situation are a variety of everyday objects. Many of these objects are capable of being used as a weight which can be combined with one of the pieces of string to form a pendulum. If a pendulum created in this way is set in motion, it is possible to pick up the end of the other piece of string, catch the end of the pendulum and tie the two together.

However this solution is rarely spontaneously produced. The reason for this result, it is argued, lies in the way that the well established, everyday functions of objects prevent the problem solver from seeing this unusual and innovative use. This basic idea is appealing because it taps experiences common to many people and to problem solving in many domains.

The area of design is no exception. Here a common and often commented on form of fixation is the premature commitment to a particular problem solution, observed in students and practitioners alike. As in other domains, the designer appears trapped by the characteristics of a possible solution that has been developed or an existing precedent solution. However, in the design domain, the majority of the discussion of this phenomena is essentially anecdotal and not based on either principled argument or the results of empirical research. Design would also appear to offer a particularly suitable domain for this approach to studying these aspects of problem solving. It is well recognised that design problems are inherently ill-defined (Simon, 1981). Consequently every design problem has the potential for innovative and creative solutions removing the necessity for specifically developing problems that have these characteristics.

While all discussion of fixation in design has been largely anecdotal, recently experimental methods have been developed for examining both whether or not the phenomena exists and, perhaps of more interest, the basis for the effect. The aim of this paper is to review the available research results and then to draw out the implications of these results in three areas. First what do the results tell us about the design process? If there are insights into the design process what are the implications for design education? Finally there is the question of the implications of the design fixation effect, (if it exists), for the role of computers in the design process. Broadly and briefly computers would appear to potentially have two types of roles in design. In one the aim is to have the computer produce the design; in the other the computer is used to provide intelligent design support system for a human designer. The first role for computers appears to have been downgraded in the past few years, largely because of the consequences of the ill-defined nature of design problems, while the second has received increasing attention. A central facet of the second computational approach to design would appear to be the reuse in some way of existing designs as in case-based systems. In this approach, a large library of designs of different types and their associated attributes is established. In the context of a particular design problem this library is searched for designs which match, using some measure of similarity, to the requirements of a particular design problem with the human designer specifying what these requirements are. Fixation effects could occur in this situation in a number of ways. However, if the *design* fixation effect exists, it could be particularly relevant to the development and use of case-based systems. The available evidence indicates that design fixation may be associated with seeing pictorial representations of possible design solutions. It would also appear to be highly likely that the design cases would contain a number of forms of pictorial representation from pictures of the completed design to various types of diagrammatic representations. The form of representation used in such systems would as a result appear to establish the conditions for fixation to occur. However, before exploring this issue further, whether or not fixation occurs and the basis of the effect needs to be established.

2. Design Fixation

Jansson and Smith (1991) were the first to develop an experimental approach to the problem of fixation in design. They argued that showing designers a picture of a potential design solution to a problem prior to a design session should result in fixation. In effect the picture would act as a precedent, blocking access to other ways of solving the problem. They also extended the argument about the basis of fixation. They suggested that the process of design involves operating on effectively two types of mental representation of the problem. One representation they refer to as the conceptual space which consists of abstract knowledge about principles, concepts and rules which can be used to solve the problem. The other representation takes the form of particular physical objects and elements which could form the physical realisation of a solution to the problem. This representation is referred to as the object space. Jansson and Smith argue that the location of the fixation induced by a pictorial representation is the object space and that innovation is prevented because the designer cannot move to the conceptual space which is where they consider that innovative changes can occur.

In order to test this hypothesis Jansson and Smith used three different types of design problem and had advanced undergraduate and practicing mechanical engineers engage in solving the problem. The experimental design was quite straight forward. For each of the design problems two groups of designers were used. One group (either a student or an expert group) were simply given a statement of the problem and acted as a control group. Separate groups corresponding in level of expertise to the control groups were given the statement of the problem together with a picture of a possible solution. The example solutions were specifically designed so that aspects were included which were incorrect given the problem statement. A set of features which characterised each pictorial example was developed and the designs produced were scored for the presence or absence of the features. The design sessions lasted for one hour and the designers were allowed to produce as many sketch designs as they liked. It would be expected that, if fixation resulted from exposure to a pictorial representation of a possible design, more features of the example should occur with the groups shown the example. This was found to be the case. For each of the design problems and for student and expert designers, more features associated with the example, including incorrect features, were found with those who had been shown the pictorial representation.

3. Exploring the Design Fixation Effect

The potential significance of this effect is apparent because of the role of precedents, generally presented in the form of pictorial and other forms of visual representations, in the teaching and practice of design. A number of significant issues relating to the effect can be identified. Does the effect occur when pictorial representations of different possible designs are presented prior to a design session? Is the effect associated specifically with pictorial representations or would similar effects occur if verbal descriptions of possible design solutions were made available? Does the effect occur with other disciplines and levels of expertise? In order to begin to explore the basis for the design fixation effect we (Purcell and Gero, 1991) carried out an experiment using one of the Jansson and Smith problems - the design of a bicycle rack for a car. Five different design solutions were identified and these are shown in Figure 1. Pictures of three of these designs were using as fixating examples (a, b and c in the Figure) and for two of these solutions a verbal description was developed (the verbal description of one of the designs is presented in Appendix 1). Novice students in architecture and industrial design participated in the experiment using the same experimental design as Jannson and Smith. Separate groups of students were shown the example design and were told that it was to illustrate what was meant by a sketch design with corresponding control groups being given only the statement of the problem. Lists of features of each design were developed and the designs produced by the experimental and control groups were scored for the presence or absence of the features. In addition the number of designs developed by each participant was recorded and the participants answered a number of questions at the completion of the session.

Differences in the frequency of design features were statistically analysed and part of the results are presented in Table 1. Effectively no evidence of fixation was found with the exception of one of the pictorial examples for one feature. The fixation effect, on the basis of these results, does not appear to be associated with simply the presentation of a pictorial example nor does it occur with a verbal description of a possible design. Where evidence for fixation was found with one of the examples, an analysis of the results of one of the questions asked at the end of the design session indicated a somewhat different possible basis for the results obtained. Participants were shown the drawings of all of the examples shown in Figure 1 and asked how familiar they were with each. Tabulation of the responses to this question revealed that the most familiar example was also the example where some evidence of fixation was obtained (see Table 1). What appears to be a fixation effect could as a result simply reflect familiarity with the example. Subsequent enquires with bicycle retailers and a group representing bicyclists demonstrated that the most familiar example was also the type of bicycle rack that predominated in sales. Interestingly this type of design was also different to the rack design that had produced fixation in Jansson and Smith's work.

There is however significant differences between our work and the original Jannson and Smith experiments. They had used advanced student and practicing mechanical engineering designers and we had used novice designers from two other disciples. A possible interpretation of the effect obtained could therefore be that novice designers from these other disciplines, lacking any domain specific knowledge, simply relied on their general, everyday knowledge which was triggered when shown the drawing of the example. This possible explanation is reinforced by the absence of any effects with the drawings of the other types of designs. This result also indicates that the effects obtained with the most familiar example do not simply involve copying as it would have been equally easy to copy each of the other types of design.

4. The Role of Design Discipline and Expertise in the Design Fixation Effect

Our next experiment attempted to examine some of these issues. We again used one of the Jansson and Smith problems - the design of a device to be used by the blind in measuring quantities for cooking. We chose this design problem because it would be unlikely that our designers would have either designed or seen an example of a design for such a device in contrast to the bicycle rack problem. In this way we were able to minimise the effects of familiarity with existing design solutions. Advanced student designers in mechanical engineering and industrial design in their final year participated in the experiment. This choice was made both because we wanted to use the designers from the same discipline as in Jansson and Smith's work and because we wanted to examine whether or not the effect occurred with different disciplines while using designers with a similar level of expertise to those in the original Jansson and Smith experiment. Industrial designers were chosen as a second discipline because the two disciplines can deal with similar types of problems. This removes a possible effect resulting from using a design discipline, such as architecture, which deals with qualitatively different types of design problems to the problem we had chosen. We also pursued the question of whether or not fixation would be found with other examples to that used by Jansson and Smith. In Australia there is a organisation which represents the blind and we approached them to determine if there were examples of such a device available. They market a device for this propose and the pictorial representations of the two examples are shown in Figure 2.

Again the same experimental design was used as in previous design fixation work. We did however introduce a change in the way the designs were analysed. In previous work features characteristic of each design were identified and each design produced was scored in terms of these features. However, in reflecting on the results of these experiments, it appeared to us that features could be of two types. One type would represent the actual details of the features present in the design example. However it is possible that a design feature could represent the same concept as was present in the design example without having the same detailed characteristics. Consequently for each design two lists of features were developed to reflect this distinction (for details of the features of each of the designs and the results of the analysis see Purcell, Williams, Gero and Colbron, 1993).

In brief the analysis demonstrated that fixation did not occur with the industrial design groups for either of the example designs. However fixation was apparent with the mechanical engineers but only with the example design used in the original Jannson and Smith experiments. This appears to indicate that fixation may occur only where the combination of the design discipline and the example design used are the same as in the original Jansson and Smith experiments suggesting that the effect may only have limited applicability. The presence of fixation in the mechanical engineers and not in the industrial designers could for example reflect differences in approaches to education in the two disciplines. While this would be an interesting result, it would diminish the general significance of the effect. However an examination of the two example designs in Figure 2 suggests another possible basis for this finding. The Royal Blind Society example is a particularly simple device that essentially uses an everyday cup with three dimensional markers identifying discrete quantities. By contrast the Jannson and Smith example is a more complex device which, significantly, appears to involve principles that could be thought of as typical of the mechanical engineering discipline. This suggests the possibility that the fixation effect is not simply discipline specific but involves the use of an example that embodies principles that are specific to a particular domain of knowledge.

5. Domain Specific Knowledge and Design Fixation

In order to test this hypothesis we sought the assistance of experts in mechanical engineering and industrial design. Our aim was to develop a new design problem which would again be the type of problem that could form a part of the practice of each discipline but where it would be unlikely that groups of advanced undergraduate students would have been involved in designing or have seen examples of solutions. We also wanted a problem where there were a number of existing solutions which both involved principles which would be typical of mechanical engineering and also examples which the experts considered unusual and innovative. The problem we identified was the design of a device for assisting the elderly into and out of a bath in a domestic setting. There are a number of existing solutions to this problem four of which are shown in Figure 3. To initially examine our hypothesis about the role of domain specific knowledge being embodied in the pictorial representation of a design, we chose the example, the Autolift device, labelled as (c) in the Figure. We had asked the experts in mechanical engineering to assess whether or not the examples involved typical mechanical engineering principles. In their judgement this example involved the use of such principles and should therefore produce fixation.

Our experiment followed the same design as previously. Advanced undergraduate students in their final year in mechanical engineering and industrial design participated in the experiment with two groups from each discipline. Both groups in each discipline received the verbal description of the problem with one group in each discipline also being shown the drawing of the example design. Lists of features related to the principles involved in the example design and the details of the design were again developed. However we considered that measuring the frequency of occurrence of design features was not the only way of assessing design fixation. For example, it could be argued that design fixation should lead to fewer designs being produced because other ways of solving the problem would not be available to the designer. Similarly fixation would be expected to produce a restriction in the range of solution types that were produced. In order to assess these other aspects of fixation, the number of designs produced by each participant was again recorded together with the type of each design produced by each participant. Design type was assessed in the following way. Brief descriptions of approximately 20% of all the designs were developed independently by two of the researchers working on the project. Similar descriptions were then grouped together to form categories which were then given type labels. This initial list of types was tested on a further sub-set of the designs before the full set of designs was coded. Designs which did not fit into any of the types were classified as "other". At the completion of the coding the "other" category was reviewed and new categories developed with the "other" category finally referring to unique designs; that is only one example of the type in the complete data set.

The results of the analyses of these various measures are present in Tables 2, 3 and 4. Table 2 (with proportions rather than raw frequencies being reported) demonstrates quite clearly that fixation had occurred with the mechanical engineering group for both features that involved principles and features involving detail. Of the seven principle features, significant differences were found between the experimental and control groups for the mechanical engineers for five of these features but only for one of these features in the industrial design groups. For the twelve detail features, the numbers of significant differences were eight and three respectively for the two disciplines. Exposing a group of mechanical engineering designers to a pictorial representation of an example design which embodies typical principles of the discipline does, as a result, appear to induce a fixation effect.

However this result is contradicted by the analyses of the other two measures of fixation. A comparison between the average number of designs produced showed no differences between the experimental and control conditions for each design discipline (see Table 3). If fixation was operating to constrain the types of solutions available to the designer such differences would have been expected for the mechanical engineering group. Similarly fewer types of design solutions should have been found where fixation occurred however this was not the case as is apparent from Table 3. The results of the analysis of the various types of data in this experiment are therefore somewhat paradoxical. In terms of the usual, feature based measures there is quite clear evidence of fixation with the predicted experimental conditions for the mechanical engineers. However with the two other measures, which would appear to be equally as reasonable as the features approach in terms of demonstrating fixation, no evidence for fixation occurred.

6. Design Fixation and Innovative Design Examples

There are a number of other aspects of the results which however are also noteworthy even though they, at least superficially, do not appear to be specifically related to design fixation. Over all of the experiments using advanced student designers there has been no evidence of fixation with the industrial design groups. In this experiment it is apparent that there are large differences between the mechanical engineering groups and the industrial designers. From Table 3 it is clear that the industrial designers produce approximately twice as many designs and twice as many types of design solutions as the mechanical engineers. It is also apparent from Table 4 that, for the industrial designers, by far the most frequently occurring type of design is "other". That is this group frequently produced, whether under the control or experimental conditions, unique, one off designs and these types of designs were very infrequently found with the mechanical engineers. These differences between the two groups, because they are effectively independent of the experimental manipulations carried out, could be interpreted, for example, as resulting from differences in educational processes in the two disciplines. It could be that industrial design emphasises creativity and difference and associates this with the idea of trying out many ideas. The emphasis on innovation and trying many different ideas would clearly produce many more designs, many more types of design and many more unique designs.

However, while these aspects of the results appear to be unrelated to design fixation, they suggest another perspective on what was occurring with the design fixation results. While industrial design may place different emphases on what is important to the outcome of a design process, it is also apparent that the areas of knowledge that make up industrial design are more diverse than those studied in mechanical engineering. It would also appear that many of these areas are associated with less well articulated bodies of knowledge than those that make up the knowledge base of mechanical engineering. For example, aesthetics plays a prominent role in industrial design education, often appearing as a separate subject, while it plays little formal role in mechanical engineering. Aesthetics also has an obviously less articulated and formal knowledge base than for example mechanics in mechanical engineering. It is possible therefore that the absence of highly articulated, formal knowledge bases in industrial design results in the absence of fixation that has been demonstrated in our experiments.

While this is a plausible, but after the event, explanation for these results, there is an alternative. It could be that it is not the absence of a highly articulated knowledge base which results in no fixation being found, but that the example used does not emphasise aspects which are considered important in industrial design. If innovation is considered important then the example used in the previous experiments, which was judged by experts from both disciplines as not being innovative, would not emphasise issues which were considered to be important in industrial design. This argument leads to the hypothesis that it may be possible to produce fixation in industrial designers by using an innovative example. One of the designs that our panel of experts considered to be innovative is example b, the Hydrocushion, shown in Figure 3. This essentially consists of a cushion which can be filled with water to the level of the bath edge to allow access, with the water then being emptied into the bath to lower the person with the process being repeated to exit the bath. If innovation is an important issue in the knowledge base of industrial designers, then this example should produce fixation. For mechanical engineers, the principles involved are not as typical, in the context of lifting weights, as are the principles involved in the Autolift example used in the preceding experiments (the second example shown in Figure 3). If fixation did not occur with the mechanical engineers it would indicate that the principles involved in an example need to be typical of the task to be performed, whereas if fixation does occur, it would indicate that activation of relevant, although not typical (in the context of lifting weights) mechanical engineering principles can produce fixation.

We therefore repeated our basic experiment using this example. Table 5 presents the features which were scored for each design that was produced. These are again divided into principle and detail features with an additional group of features relating to aspects of the context that is depicted in the example drawing. In this design example we identified six principle features. However an examination of the list demonstrates a number of the features were not unique to this particular type of design with these features resulting from general constraints on the design eg a removable device or a device which can raise or lower the person in the bath. In effect what characterises this design and makes it innovative is the use a single basic principle - the use of water pressure which is already present in the design context - to resolve many of the design issues. This contrasts with the lists of features associated with the Autolift example. Here the principle features actually identify a series of principles which solve various parts of the problem. The detail features are again those that directly reflect the specific ways in which the principled features are realised in the fixation example. The contextual features are those which are present in the fixation example but either represent expected parts of the design context eg tiles on the adjacent wall or are ancillary drawings which illustrate other views of the device and ways in which the device can be used.

Table 5 also presents the proportions representing the occurrence of each of these features in the experimental and control groups for the two design disciplines. Because of the small pool of final year industrial design students that are available in Sydney, only thirteen individuals have participated in this part of the experiment to date with however twenty mechanical engineering students participating. As a result of the unequal numbers in the groups, statistical analyses have not been carried out yet. In order to allow a comparison between the results of the two experiments, the results are expressed in terms of proportions rather than raw frequencies with the potentially significant differences (based on previous analyses) being identified by asterisks. A comparison between Tables 3 and 5 identifies a number of interesting differences and similarities between the two experiments. With the Autolift device and the mechanical engineering group, there was clear evidence of what appears to be fixation in the significant differences between the experimental and control groups on the majority of both the principle and detail features. This pattern does not appear to occur with the innovative design example with this group. One principle feature - operates on water pressure - is clearly different between the experimental and control groups with no designs in the control group exhibiting this feature. The features relating to raising and lowering the individual and connecting the device to the existing water tap may demonstrate an effect. With the detail features only one - the presence of a rectangular platform as part of the design - may be significant. It is also apparent that many of these detail features, which show no evidence of differences, are very specifically related to this type of design and are not likely to be present in other types of designs. For example the last six of the detail features are quite specifically associated with a device of the type pictured. However these features are effectively missing from the designs that were produced. The results using the innovative example with this group therefore indicate that fixation is associated with the principles involved in the example design and that the designs produced do not reflect the details of the example.

The pattern of results with the industrial design student group is however quite different. There may be a difference between two of the principle features - the device is used to raise and lower the individual from the edge of the bath and the device is removable and two of the detail features - the device has a platform seat with rounded corners. However it is apparent that these features are not specifically associated with the example device that uses water pressure and a water filled container. It therefore appears that, for this group, there is essentially no indication that any of the devices produced in either the experimental or control groups used this innovative approach to the design of the device because neither the principled or detailed features that are specifically associated with this type of design are present in the designs produced. The absence of any fixation effect with this group is therefore similar to the results in the previous experiment however the implications of the result in this case may be quite different.

The results with the contextual features are also of interest. For the mechanical engineers differences appear to be associated with two of the types of features which would be consistent with the use of a water filled device - placing the device at the opposite end of the bath to the taps and showing a single bath tap. It is also apparent that many more potentially significant differences are associated with the contextual features than with either the principle or detailed features. Further many of these differences are associated with what might be referred to as conventions associated with the development of a sketch design. For example, the set of features which involve using additional insets which illustrate how the device can be used are quite typical techniques that are used during design development. The reasons why more of these types of features appear in the results of those groups shown the design example across both design disciplines is not immediately apparent.

7. Conclusions

Design Fixation, Design Education and the Design Process

The results of this final experiment have potentially important implications. The initial conception of design fixation was that it represented an impediment to innovative design. Designers shown an example demonstrated a lack of flexibility in their design process because they reproduced the characteristics of the example shown. Often this lack of flexibility also extended to reproducing faults that were present in the example design. While this effect resulted from being shown an example design, it could be extended to the more typical design situation. Designers often look at precedent designs and could become fixated in this way. Even more typically, designers, once they have produced a drawing of a potential solution, could become fixated on that solution - an effect often commented on by designers and by those who teach design.

However the results of this series of experiments point to a different perspective on the fixation effect. Fixation appeared in our initial experiments to be associated, if it occurred at all, with the absence of domain specific knowledge and a reliance on everyday knowledge activated by exposure to a picture of a familiar example. When the familiarity effect is removed and the type of problem is matched to the discipline of the designer, the results indicated that fixation only occurred with one discipline - mechanical engineering - and only with an example design that embodied principles that formed a part of the knowledge base of that discipline. With the other discipline - industrial design - there was very little evidence of fixation. The role of principles specific to a discipline in producing fixation was demonstrated by using a problem that would not involve the familiarity effect combined with an example solution which was judged by experts to involve knowledge that would be typical of the mechanical engineering discipline. However, while this effect was found when features associated with the example were analysed, two other measures of fixation - the number of designs produced and the number of solution types - showed no fixation effects. Again no fixation effects were found with the industrial designers but there were notable differences between the two disciplines. Industrial designers produced many more designs, many more types of design and many more one off designs. These effects were independent of whether or not an example design was shown.

While these differences between the two disciplines could reflect differences in educational processes, it was argued that the absence of the effect with the industrial designers could result from the use of example designs that did not embody aspects relevant to that discipline. The fact that the participants from this discipline produced many more designs, many more types of designs and many more one off designs suggests that there is a focus on innovation in this discipline. If this is correct an innovative example design should produce fixation for this discipline. Once again however no evidence was found for fixation with this discipline but evidence for fixation was again found with the mechanical engineers.

However consideration of the attributes of the innovative design and the results with both disciplines suggests that fixation as it has traditionally been conceived may not be the appropriate way to look at the results using this example. The example design used is innovative both because it uses a principle which is not typical of the general approach to lifting weights and because it uses a single principle to resolve a number of the design issues. The results with mechanical engineers demonstrated that what we have normally referred to as fixation was really associated with a concentration predominantly on the core innovative principle involved in the example design - the use of water pressure to raise and lower the individual - with many of the specific aspects of the example design not being found in the designs produced. While the industrial designers showed no evidence of fixation, they also failed to produce any designs which used this innovative approach in either the experimental or control groups.

This way of looking at the results raises a number of issues. Is it that the use of typical examples produces the traditional fixation effect while the use of innovative examples focuses the designer on the principles involved? Does this then result in designs that explore and develop the application of this innovative principle? We are currently investigating aspects of these designs to determine if they exhibit these characteristics. If this is the case it suggests that, for example, at least part of the use of precedents in design education should involve the deliberate use of and focus on innovative example designs. While innovative designs are discussed and analysed in design education, it may be that this is not effective and that the use of such designs should take the form of showing them prior to a design session with the analysis coming after the session has been completed.

The absence of either type of fixation effect with the industrial designers also raises a number of particularly interesting issues. The production of large numbers of designs of many different types would appear to indicate that these designers were attempting to be innovative. The absence of any fixation in the experiments where the "traditional" fixation effect is found with the mechanical engineers would appear to indicate that this approach perhaps prevents the occurrence of fixation effects of this type. However it is possible that what occurs in fact is a search for difference rather than innovation. The absence of any examples of the innovative design approach represented by the example in the final experiment with this group could reflect just such a process of searching for difference. If this is the case and it represents the results of the educational processes used in this discipline, it indicates that the potential benefits available from innovative design will not be available to the discipline.

The results of our research to date may be summarised in the following way. Fixation in the traditional sense may well be found where designers are forced to rely on everyday knowledge. Mechanical engineers become fixated in the traditional sense when the example they are shown embodies typical principles which are characteristic of the knowledge base of the discipline. When shown an innovative example, where the principle involved is unusual in the context and / or resolves many of the design issues using a single principle, mechanical engineers become "fixated" on the principle involved and appear to then explore ways of solving the problem using the principle. Industrial designers appear to show no evidence of fixation under any of the experimental conditions we have employed. However, while showing no evidence of "traditional" fixation, the industrial designers showed no evidence of producing innovative designs using the principle involved in the innovative example. In a sense these groups may have become "fixated" on being different. "Fixation" therefore appears to possibly exist in a number of forms and we as researchers need to be wary of becoming fixated on our conception of what fixation is.

Design Fixation and Computational Approaches to Design

Given these results from our research it is possible to return to the issue of the relationship between fixation effects and computational approaches to design discussed at the end of the Introduction to this paper. A major finding of this research was that there are differences between the two design disciplines studied in our project. With the mechanical engineers, fixation in the traditional sense of reproducing the characteristics of a design, including incorrect features, occurred where the example shown embodied principles that were typical of the knowledge base of the discipline. If the cases included in a case - based mechanical engineering design support system both embodied principles typical of the discipline and either contained mistakes or features that were inappropriate in relation to the particular design problem being addressed, then fixation effects that are negative in terms of the design outcome for the particular problem are likely to occur. However, if the design examples that are presented are innovative, it appears likely that designers may identify the principle involved and then explore how this could be used in the particular design situation.

This latter outcome points towards ways in which such systems might be used to both encourage innovative design and prevent design fixation effects. This could be done in at least two ways. The cases that were included in the system could be deliberately selected so as to include a range of examples that went from the typical to the atypical within any particular type of artefact. In addition the similarity metric which is used to identify relevant cases could be designed so that cases of other types that have relevant features could also be retrieved providing further possibilities for exploration of the implications of these ideas and increasing the possibility of innovation in design. These approaches however would not necessarily prevent the first type of fixation occurring. For example if the cases that are retrieved first all embody typical principles in the field then fixation of the first type could occur with the designer not proceeding to explore the further possibilities of the system. This suggests that it would also be necessary to carefully consider the issue of the order in which such a system retrieves cases and that the process of learning to use such systems should specifically be designed to make users aware of these issues.

The results with the industrial designers have equally important but more general implications for the design of such systems. The evidence from our work is that presenting pictorial examples has no effect on the designs produced by the participants from this discipline. Taken at face value this would indicate that there would be little point in developing a case - based design support system for this discipline as it would be unlikely to have any effect. In fact our results would lead to the prediction that such a system would be unlikely to be used as a result of designers from this discipline being “fixated” on difference. This in turn raises some very basic issues about the education of industrial designers which cannot be addressed here but which point to the need for further research in the area of industrial design to establish the generality of the effects we have observed.

References

Jansson, D.G. and Smith, S.M. (1991) Design fixation. *Design Studies*, 12, 3-11.

Maier, N.R.F. (1931) Reasoning in humans : II. The solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology*, 12, 181-194.

Purcell, A.T. and Gero, J.S. (1991) The effects of examples on the results of a design activity. In Artificial Intelligence in Design ‘91 Ed. J.S. Gero, Butterworth - Heinemann: Oxford, pp 525-542.

Purcell, A.T., Williams, P., Gero, J.S. and Colbron, B. (1993) Fixation effects : Do they exist in design? *Environment and Planning B : Planning and Design*, 20, 333-345.

Purcell, A.T., Gero, J.S., Edwards, H.M. and Matka, E. (1994) Design Fixation and Intelligent Design Aids. In J.S. Gero and F. Sudweeks (Eds) Artificial Intelligence in Design ‘94, 483-495,Kluwer Academic Publishers, The Netherlands.

Simon, H.A. (1981) The Sciences of the Artificial (2nd. edition) M.I.T. Press : Cambridge, Massachusetts.

Wertheimer, M. (1982) *Productive Thinking*. University of Chicago Press : Chicago.

Acknowledgments

The research reported in this paper was supported by Grant Number A89231572 from the Australian Research Council to A.T. Purcell and J.S. Gero. Part of the material presented in Section 3 of the paper was reported in Purcell and Gero (1991); part of the material in Section 4 was reported in Purcell, Williams, Gero and Colbron (1993) and part of the material in Section 5 was reported in Purcell, Gero, Edwards and Matka (1994).

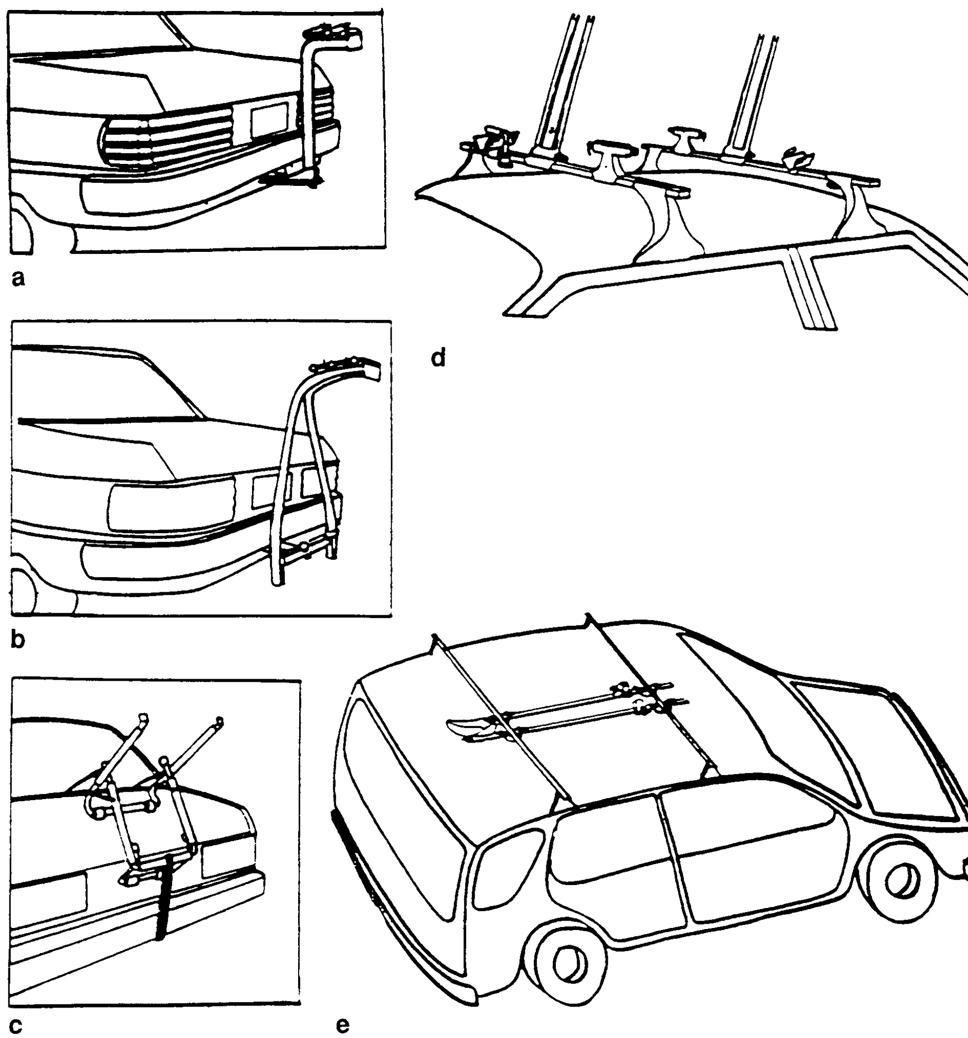

Figure 1. Five types of bicycle-rack design; (a) single-post, (b) A-frame, (c) boot, (d) upright, (e) seat-and-wheel

Figure 1 Illustrations of five bicycle rack designs.

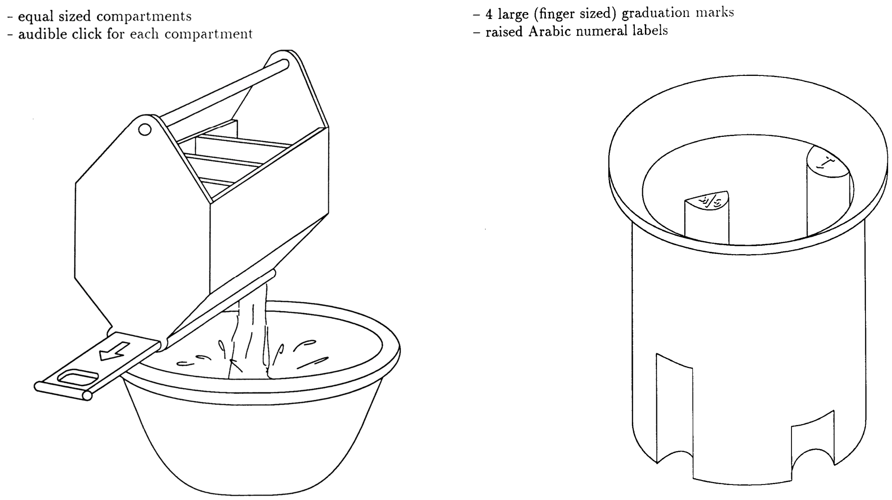

Figure 2 Illustrations of the two example designs of devices for use by the blind in measuring quantities for cooking.

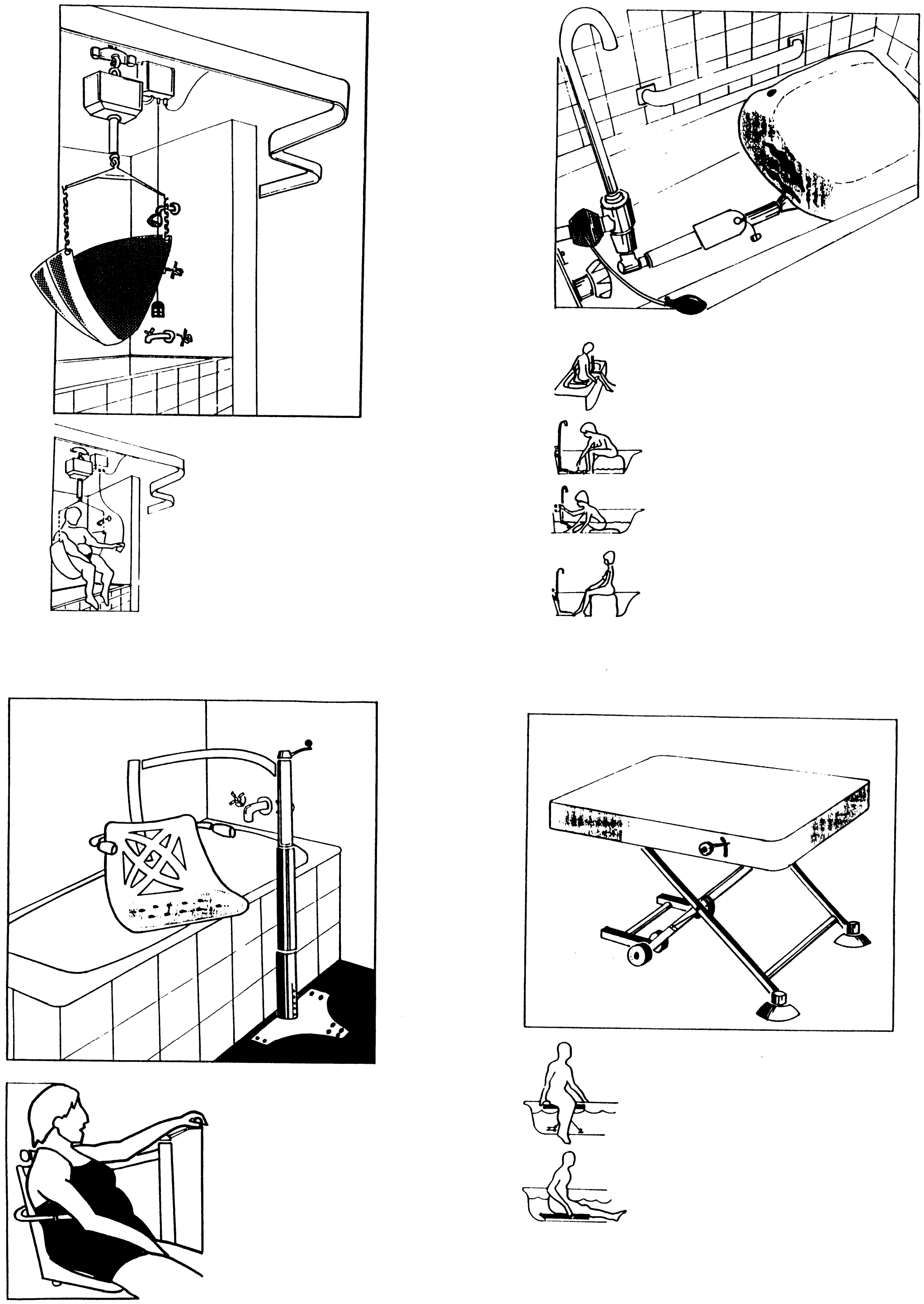

Figure 3 Illustrations of four devices designed to assist the elderly in entering and leaving a bath.

Table 1 Probability of the difference in frequency of occurrence of four bicycle design features between experimental and control groups.

Group	Location of rack	Car attachment	Bicycle support	Bicycle attachment
Control versus single-post picture	0.36	0.38	0.53	0.17
Control versus single post description	0.83	0.88	0.72	0.06
Control versus A-frame picture	0.79	0.64	0.21	0.02
Control versus A-frame description	0.3	0.13	0.61	0.12
Control versus boot picture	0.89	0.99	0.86	0.26

Table 2 Proportions of two types of features found for the experimental and control groups in two design disciplines for the bath access problem with the Autolift fixating example (statistically significant differences (.05) are identified with an asterisk).

		Mechanical Engineers		Industrial Designers	
		Experimental	Control	Experimental	Control
Principles	Fixed	* .72	.42	.52	.34
	Fixed to floor	* .25	.06	* .16	.04
	Column	* .36	.06	.14	.05
	Lifting mechanism within	* .23	.03	.06	.04
	Handle on column	.03	.00	.03	.00
	Boom	* .31	.03	.11	.06
	Seat	.67	.44	.63	.55
Details	Fixed with base plate	* .22	.00	* .09	.01
	Fixed with bolted base plate	* .14	.00	.05	.00
	Column - tripartite	.00	.00	.03	.00
	Bolts on column	.00	.00	.02	.00
	Winder with knob	.03	.00	.02	.00
	Rigid boom	* .28	.00	.08	.05
	Moulded seat with back	* .44	.14	* .38	.10
	Perforated seat	* .17	.03	.09	.03
	Arms on seat	* .31	.08	.09	.05
	Incorrect orientation to taps	.08	.03	.03	.00
	Orientation of bath as in example	* .44	.11	* .48	.13
	Tiles on bath as in example	* .25	.00	.05	.00

Table 3 Number of designs and number of solution types produced by the experimental and control groups in two design disciplines for the bath access problem, Autolift fixating example.

	Industrial Design			Mechanical Engineering		
	Control	Autolift	Inflatable Cushion	Control	Autolift	Inflatable cushion
Average number of designs	3.8	3.4	3.1	1.8	1.7	2.1
Average number of solution types	3.2	2.9	2.8	1.7	1.5	2.0

Table 4 Frequencies of solution types for the bath access problem produced in the experimental and control groups in two design disciplines, Autolift fixating example.

Solution Type	**Mechanical Engineers**		**Industrial Designers**	
	Experimental	Control	Experimental	Control
Ledge	2	0	2	4
Static rim seat	0	0	1	3
Swivel seat	5	5	9	6
Slide	0	0	1	2
Inflatable cushion	0	2	1	9
Scissor lift	0	4	2	7
Overhead pulley	9	4	2	5
Boom seat with column	9	0	4	2
Door in side of bath	1	1	2	1
Other bath alteration	0	2	3	2
Step and rail	2	5	5	6
Tracks and racks	3	4	7	2
Grip rails	1	4	6	6
Other	4	5	22	28
Total	36	36	64	80

Table 5 Proportions of three types of features for the experimental and control groups in two design disciplines with the Hydrocushion fixating example (possible significant differences are identified with an asterisk).

		Mechanical Engineers		**Industrial Designers**	
		Experimental	Control	Experimental	Control
Principles	Operates on water pressure	* .29	.00	.00	.0
	Used to raise and lower person from edge of bath	* .44	.28	* .50	.3
	Device is removable	.51	.50	* .67	.5
	Device connects to existing faucet	* .15	.00	.00	.0
	Valve to direct water flow	.07	.00	.00	.0
	Provision made for overflow when device is raised	.02	.00	.00	.0
Details	Water filled container	.12	.00	.00	.0
	Inflatable cushion	.15	.06	.06	.0
	Platform seat, no sides or back	.27	.19	* .42	.3
	Rectangular platform	* .27	.11	.19	.1
	Rounded corners	.17	.11	* .22	.0
	Connection to faucet via an inflatable pressure collar	.02	.00	.00	.0
	Collar attached by a hand squeeze pump	.02	.00	.00	.0
	Cushion connects to faucet via number of pipes	.02	.00	.00	.0
	Fixed piping incorporating a rightangle	.02	.00	.00	.0

	Insert plug to fill cushion, release plug to drain water		.02	.00		.00	.0
	J shaped vertical pipe connected to faucet		.05	.00		.00	.0
Context	Unit in intended environment		.90	.97	*	.92	.7
	Device or user at opposite end to taps	*	.27	.08	*	.19	.0
	Bath positioned in return		.12	.19		.14	.0
	Handrail located above bath fixed to tiled wall surface		.02	.06		.03	.0
	Tiles shown		.07	.03	*	.17	.0
	Single bath tap shown	*	.12	.00		.00	.0
	Insets or series of illustrations used		.73	.64	*	.86	.5
	i) User operating the unit	*	.39	.19	*	.44	.2
	ii) Rear perspective of user seated on unit in bath		.02	.00		.03	.0
	iii) User lowering device	*	.22	.00	*	.14	.0
	iv) User raising the device		.10	.00		.06	.0
	v) User on raised device ready to leave bath		.07	.03		.03	.0
	vi) Side elevation shown	*	.51	.28	*	.36	.2
	vii) Schematic representation plan or section view		.56	.64	*	.61	.5

Appendix 1

Instructions for verbal description fixation group

The aim of the design exercise is to come up with a sketch design(s) for a bicycle rack for three bicycles for a car. The bicycles have to be held securely, and without damage to either the bicycle or the car. The bicycles must not extend beyond the overall width dimension of the car to avoid potential damage to people or vehicles in passing.

There are a number of key issues to be considered in the design of a bicycle rack. The first is the way in which the rack is attached to the car. Then, there has to be a structural system that will support the bicycles. Third, there has to be a way of attaching the bicycles to the support system. Fourth, both the structural system and the way of attaching the bicycles have to have the correct relationship to fulfil the other more general conditions of safety etc. To illustrate , the bicycle rack can be attached to the car at a number of locations : for example at the rear of the car, to a tow bar fitting, or directly to the chassis of the car. The bicycles can be sup[ported structurally in a number of ways : for example, two steel posts in the shape of an A joined across the bottom of the A can be attached to the fitting fixed to the car. This has to be of sufficient height to provide clearance above the ground. Similarly the bicycles can be attached to the rack in a number of ways : for example, they can be held by the top horizontal section of the bicycle frame in short half sections of pipe of a diameter that allows the bicycle frame section to fit into the pipe with the other half section closing over the bike frame. The bicycles then have to have the appropriate relationship to the car : for example, to the top of the A - frame a small steel section can be attached at rightangles in line with the length of the car. The fitting with the brackets attaching the bicycles can be placed at rightangles to the length of the car on this section of the post, with the bicycles being placed parallel to and clear of, the boot of the car.

Detailed and accurate drawings are not required : simple, rough, outline sketches are all that is needed. In addition to the sketches, you can write comments on the drawings to illustrate what you mean. You will be allowed 45 minutes in which to complete the sketch design. If you wish you may complete more than one design.

This is a copy of the paper: Purcell, T. A. and Gero, J. S. (1996) Design and other types of fixation, *Design Studies* **17** (4): 363-383.