DESIGN FIXATION AND INTELLIGENT DESIGN AIDS

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Abstract. Rather than replacing a human problem solver, computers are increasingly seen as intelligent aids to problem solving. In this role the computer's capacity for storing and rapidly retrieving large amounts of information can potentially significantly augment human problem solving. In the specific context of design problem solving, this approach has particular attractions when associated with recent advances which allow the inclusion of graphic as well as textural material. Rather than simply providing information about principles and descriptions of examples of their use to solve problems, computers could generate sets of plans, perspective drawings and even sets of pictorial representations of actual design solutions to particular types of problems. However, while this may make such systems very attractive to designers, this very richness of information may produce a significant problem for design. Design fixation involves the reproduction of both appropriate and inappropriate aspects of an example design when the example solution is shown as part of the statement of the design problem. The results of the experiment to be reported indicate that the fixation effect does not simply depend on the pictorial representation of a possible solution to a problem. Rather fixation depends on the picture embodying principles which form a part of the knowledge base of the design discipline. It is likely that the cases representing previous solutions to a problem contained in an intelligent design aid would predominantly be of this form and could therefore establish the conditions for fixation to occur. While this could in fact be beneficial where routine design is involved, it places severe constraints on innovative or creative problem solving.

1. Introduction

There has been increasing interest in two related issues which represent departures from much of the original work in the context of human problem solving and Artificial Intelligence (AI). At a basic level, the initial approach to this issue in AI involved the assumption that human problem solving involved the manipulation of symbols and the use of abstract knowledge.

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Given this view of AI, the human problem solver could (perhaps only ultimately) be replaced by a computer because computers are designed for particularly effective manipulation of symbols. By contrast, more recent views of human problem solving and cognition generally have emphasised the role of more specific knowledge associated with particular, previously encountered instances or cases in the particular problem solving area together with more abstract knowledge (Kolodner, 1985; 1989; Schank and Riesberg, 1989). Associated with this shift has been a change in the way the role of the computer is conceptualised in problem solving generally and design in particular. Rather than the computer replacing a human problem solver, computers are now seen as, possibly intelligent, problem solving aids storing large amounts of data and retrieving relevant information to the problem at hand in the form of previous cases. These two issues are related in the sense that a particularly useful intelligent design aid would be one that could produce "similar" instances or cases of solutions to the problem being addressed.

While this view of the role of previous instances or cases in problem solving developed from a consideration of issues in the general area of learning and knowledge representation, the use of previous instances in this way has a substantial history in education and particularly in the education of designers. Here instances or cases are referred to as precedents and it is the study of the actual physical object or various types of visual simulation of the object which forms the basis of the learning experience. Generally the intent of the teacher is that the student should learn the principles which are exhibited in the precedent case that is presented. However it is possible that the uses of cases in this format may have an unintended effect. Jansson and Smith (1991) found that showing an example of an object that was to be designed as part of the statement of the problem resulted in advanced student and practising mechanical engineering designers reproducing the characteristics of the example design in their solutions. This occurred even where there were characteristics of the examples which resulted in inappropriate designs which specifically contravened aspects of the design problem as stated. Jansson and Smith (1991) referred to this effect as design fixation to specifically relate it to the earlier work by the Gestalt psychologists where similar impediments to human problem solving had been demonstrated. The potential relevance and importance of this effect to the newer view of computers as intelligent problem solving aids is apparent, particularly in the context of design where the precedent cases are highly likely to involve pictorial representation of the actual artefact. It is possible that, rather than being an intelligent design aid, a computer could act as a particularly effective source of design fixation. The conditions which produce design fixation are as a result of some significance in the context of

AI in design and the experiment to be reported was designed to develop further insights into this effect.

2. Design Fixation and the Conditions Which Produce It

In a replication of the original experiment, Purcell and Gero (1991) used one of the design problems from Jansson and Smith (1991) - the design of a bicycle rack for a car. The designs of architectural and industrial design students were compared with different groups of students from the two disciplines being given either simply a statement of the problem, the statement of the problem together with a sketch of one of three possible designs, one of which had been used by Jansson and Smith (1991) or a statement of the problem together with a verbal description of one of the designs represented pictorially. The aim of this experiment was to replicate the original Jansson and Smith effect, to determine whether fixation occurs with *any* example represented in pictorial form and whether the effect would occur with a detailed verbal description of an example as well as with a pictorial representation. Fixation effects did not occur with all of the pictorially presented example designs and was not associated with the verbal description of the example design. Fixation appeared to be associated with one of the example designs, however this was also the type of design that is experienced most frequently in everyday life. It was therefore not possible to decide whether the designers were simply using available, everyday knowledge rather than being affected by the pictorial representation of the example design. The result could also have been affected by differences between the participants in the two experiments. Jansson and Smith (1991) had used advanced undergraduate and practising mechanical engineering designers while participants in this experiment were at the beginning of their design education in different disciplines to mechanical engineering.

Subsequently Purcell, Williams, Gero and Colbron (1993) examined the issues of the effect of everyday familiarity with design solutions and the differences in discipline background and level of expertise. The question of everyday familiarity was addressed by using another of the original Jansson and Smith design problems - the design of a device, to be used by the blind, for measuring quantities to be used in cooking. With this design problem it would be unlikely that participants would have actually seen an example of a solution to the problem. Advanced undergraduate students participated in the experiment from mechanical engineering, giving designers of a similar level of expertise to those used by Jansson and Smith together with participants from industrial design at the same stage in their education as the mechanical engineering students. The Jansson and Smith pictorial example was used with groups from the two different design disciplines. In addition groups from the two disciplines were also shown a pictorial representation of a quite different type of design solution. Fixation was measured in two ways. First it could be in terms of superficial features which were those which reproduced specific perceptual aspects of the design. Second fixation could be in terms of analogical features where aspects of the design exhibited features which involved the same principles as were used in the example. Clear fixation effects were found with only one of the design disciplines and for only one of the pictorial examples. Fixation was found with the mechanical engineering students and with the example design used by Jansson and Smith. No evidence of fixation was found with the other design example with the engineering students and for either of the groups of industrial design students. Fixation was also more apparent for the analogical features of the design indicating that fixation was not simply a result of copying perceptual features of the example design. While there are a number of possibilities which may account for these results, one appears to be of particular interest. A comparison of the two example designs demonstrated that one, the Jansson and Smith design, clearly involved knowledge and principles that would be a part of mechanical engineering expertise while the other design, based around a cup, embodied simple, everyday knowledge that would be similar for the groups from the different design disciplines. This suggests that fixation may depend on the use of pictorial examples which represent knowledge which is part of the expertise of a particular discipline. The aim of the experiment to be discussed was to test this hypothesis about the basis of design fixation. In the context of intelligent design aids, it is apparent that this proposal regarding the basis of design fixation is particularly significant. If design fixation depends not only on the use of a pictorial example but an example embodying principles and knowledge typical of the field then these are precisely the most likely examples to be made available by an intelligent design aid which accesses previous design cases.

3. Experimental Design

Undergraduate students in their final year of mechanical engineering and industrial design participated in the experiment again providing levels of expertise similar to the groups used in the Jansson and Smith (1991) experiment. The problem chosen was to design a way of providing assistance to the elderly in getting into and out of a bath in a domestic setting. It was specified that the users would be elderly people who were reasonably independent but who would experience difficulties associated with normal ageing such as diminished muscular and joint function and sensory perception. This particular problem was chosen for a number of reasons relating to our previous work. First, based on discussions with academics in both disciplines with extensive professional experience, it was the type of problem which was both unlikely to have formed a part of the design experience of the participants and they would also be unlikely to have seen examples of existing design solutions. As a result the possible confounding effect of "expert" and everyday experience with examples was removed. Second, while the problem was unlikely to have been attempted previously, the discussions with mechanical engineers and industrial designers indicated that, while it was not a typical problem for either discipline, it was the type of problem that practitioners in both disciplines could be asked to solve. This particular design problem as a result removes the difficulty associated with our earlier experiment (Purcell and Gero, 1991) where the participants were asked to solve a problem from outside the range of problems that would normally form a part of the particular design discipline.

While the design problem has these characteristics, there are also existing solutions which represent a number of different ways of approaching the problem. This allowed the selection of a fixating example which clearly embodied principles which form a part of the expertise of the mechanical engineering discipline and consequently according to our hypothesis should result in fixation in this group but not with the industrial design students. The particular design example chosen is shown in Figure 1 in the format that was presented in the experimental conditions. The control conditions involved simply a verbal statement of the problem. All groups were asked to produce sketch designs however, for the experimental conditions, participants were given the verbal statement of the problem and, on a separate page, the pictured example. Participants were told that the picture was to illustrate what was meant by a sketch design. In summary, one group from each discipline received the control instructions and one group from each discipline the statement of the problem together with the pictorial example. The problem statement given to the control group is presented in Appendix A and the problem statement given to the experimental group is presented in Appendix B. A total of 37 mechanical engineering and 16 industrial design students participated in the experiment with 17 and 7 participants from each discipline in the experimental conditions and 20 and 9 in the control conditions.

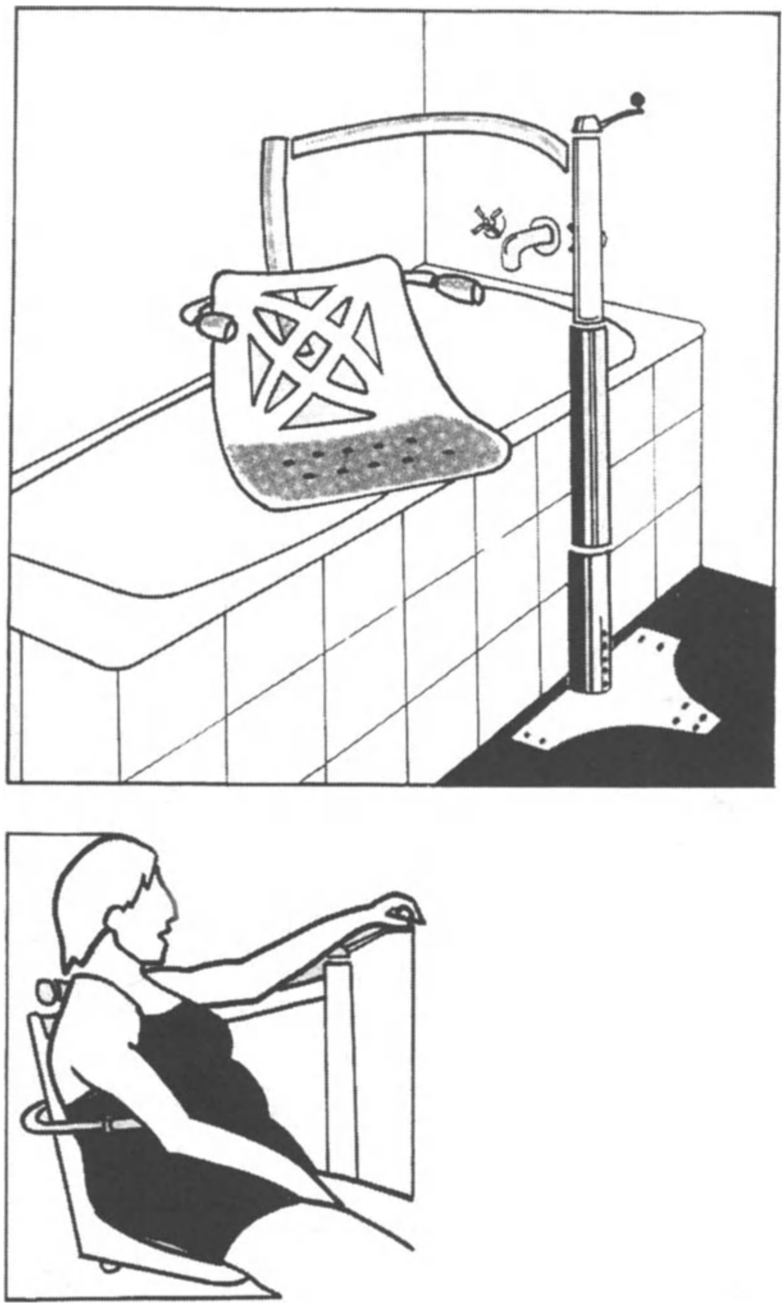

Figure 1. The design example which was shown to students in the experimental condition.

4. Results

Participants were allowed to produce as many sketch designs as they wished and were asked to indicate, at the end of the session, which was their most preferred design. The following analysis is based on the subject's preferred sketch design. The two sets of measures used in the previous experiment which were based on the frequency of occurrence of superficial and analogical features were also used in the analysis of these results. The presence or absence of each feature in each sketch design was recorded. Tables 1 and 2 present descriptions of the two feature sets and the frequency of occurrence of each feature in designs produced by mechanical engineers and industrial designers in the control and example conditions.

TABLE 1. Symbols for analogous features and frequency of occurrence of each feature in each condition.

		Mechanical Engineering		Industrial Design	
Symbol	Description	Control (n=20)	Example (n=17)	Control (n=9)	Example (n=7)
A_1	Fixed	6	11	3	3
A_2	Fixed to floor	0	6	2	0
A_3	Column	0	9	1	0
A_4	Lifting mechanism within	0	7	1	0
A_5	Handle on column	0	1	0	0
A_6	Boom	0	8	1	0
A_7	Seat	7	12	4	3

Figures 2 and 3 show the results of a t-test comparing the experimental and control samples in terms of frequency of occurrence of the analogical and superficial features. In each figure the line marked with a diamond represents the value of t for each feature for the mechanical engineering subjects (37 subjects in two samples, degrees of freedom = 35), while the lower line identified by pluses represents the t-test value for the industrial design students (16 subjects in 2 samples, degrees of freedom = 14). The probability of occurrence is represented on the ordinate of the graphs and the 0.05 and 0.01 criteria are marked. For example, in Figure 3, it is apparent that superficial feature S_7 ("moulded seat with back") was produced significantly more often ($p<0.05$) by the mechanical engineers in the experimental group than their counterparts in the control group, whereas for the industrial designers there was no significant difference in this feature.

TABLE 2 . Symbols for superficial features and frequency of occurrence of each feature in each condition.

		Mechanical Engineering		**Industrial Design**	
Symbol	**Description**	**Control** (n=20)	**Example** (n=17)	**Control** (n=9)	**Example** (n=7)
S_1	Fixed to base plate	0	5	0	0
S_2	Fixed to bolted base plate	0	4	0	0
S_3	Column - tripartite	0	0	0	0
S_4	Bolts on column	0	0	0	0
S_5	Winder with knob	0	1	0	0
S_6	Rigid boom	0	7	0	0
S_7	Moulded seat with back	3	8	1	2
S_8	Perforated seat	0	4	0	1
S_9	Arms on seat	2	4	1	1
S_{10}	Incorrect orientation to taps	0	2	0	0
S_{11}	Orientation of bath as example	2	8	3	5
S_{12}	Tiles on side of bath as example	0	5	0	1

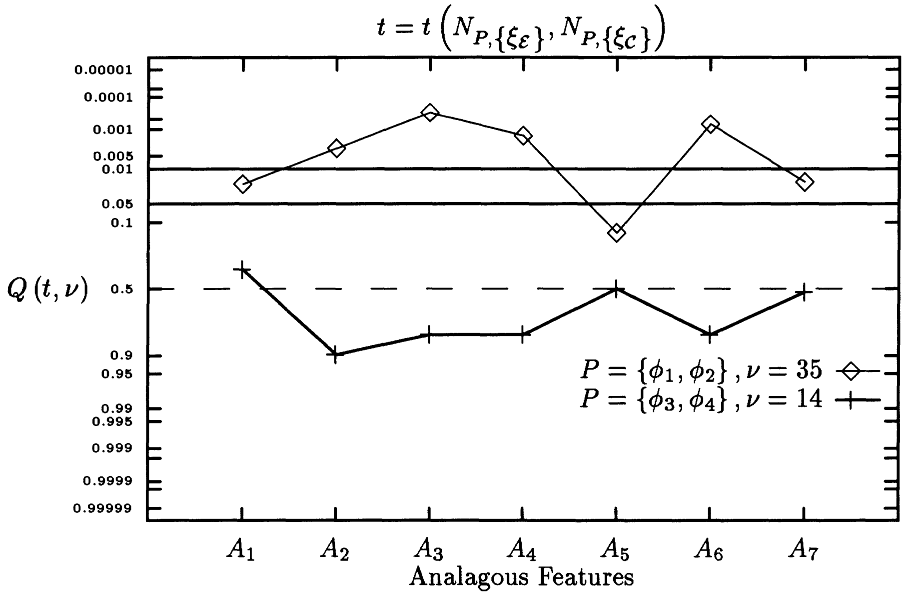

Figure 2. t-test results for analogous fixation features

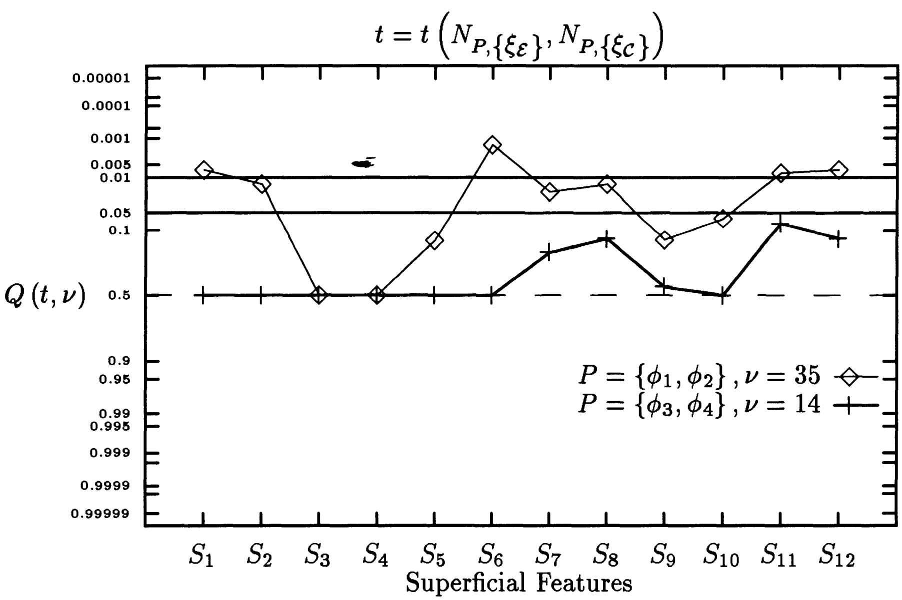

Figure 3. t-test results for superficial fixation features

5. Discussion

The results of this analysis appear to be quite clear-cut. The mechanical engineering students were fixated and the industrial design students showed no evidence of fixation. The results with the industrial designers should be treated with some caution because of the relatively low numbers of participants from this discipline. However the procedure used to test for the difference between the experimental and control groups is specifically designed to take account of low frequencies and as a result minimises the likelihood of the absence of a significant difference with this design group being due to this aspect of the experiment. There is also an interesting difference between the results for the superficial and analogical measures of fixation in the mechanical engineering group. There are twelve superficial and seven analogical features with a significant difference being found for seven of the twelve superficial features and six of the seven analogical features. This result demonstrates that, while fixation occurred for both types of features, it was most apparent in relation to the analogical features. As in our previous work this difference is evidence against any simple view of fixation being the result of the designers simply reproducing the attributes of the example design. Design fixation as a result appears to depend on the designer being exposed to a pictorial representation of a solution which embodies principles which form a part of the expertise of the design discipline. Clearly the generality of this effect needs to be tested, for example in the case of industrial designers, by using pictorial representations of solutions embodying principles that would be typical of that discipline. Further, given that Jansson and Smith (1991) demonstrated fixation effects in a similar student group and with practising mechanical engineering designers, it would appear that this may not be a phenomenon only associated with student designers, however this possibility is to be addressed in future experiments using experienced designers.

If however the importance in design fixation of the pictorial representation of a design using principles from the area of expertise of the designer is accepted, they have significant implications for the development of intelligent design aids using a case based approach. Given that such an aid would be developed in the context of a particular design discipline, the cases presented to a designer, if they contained pictorial representations associated with the design, would be likely to produce fixation. If the way of solving the problem is appropriate, then the fixation produced could be viewed as beneficial. However this would appear to require that the problems be well defined and, as a result, does not take account of the ill-defined nature of design problems (Simon, 1973; Reitman, 1975). For example, in the context of this specific design problem, the example used represents both well known mechanical principles and a use of these principles in a way that is typical in a situation that is familiar to the designers - that of devices used in an industrial setting for raising and lowering heavy objects. While the device which produced the fixation performs the required functions, it could be argued that, in the context of a domestic bathroom being used by the elderly, it represents an inappropriate and certainly not an innovative solution.

One way of avoiding the undesirable effects of fixation produced by pictorial examples could be to present the information which is accessed by a designer in the form of a *description* of the principles and the ways of implementing those principles that have been used in previous designs combined with an evaluation of the devices. On the basis of our previous research showing a lack of fixation using descriptions of designs, this could circumvent the deleterious effects of fixation while activating abstract, conceptual knowledge from which designs could be developed. Because the knowledge accessed in this approach would be specifically about previous design responses to the *same* problem, the absence or difficulty of transfer between conceptually related problems found in the analogical problem solving literature should not occur in this situation (Gick and Holyoak, 1980). The weakness of this approach however is that it is unlikely to generate innovative ways of solving the problem simply because the available information is confined to the domain of previous design solutions. This effect could, in part at least, be offset if the domain of previous solutions varied widely in the way the problem was solved and in the innovativeness of the design approaches rather than simply representing different design solutions using effectively the same or very similar principles. This is because there is some evidence that exposure to a number of different ways of solving a problem leads to more flexible problem solving (Brown, 1989). This research is also particularly relevant because the alternative ways were presented in the form of the actual objects and materials and their arrangement that were used to solve the problem; that is in a form that is very similar to a pictorial representation. It is possible therefore that fixation occurs with the presentation of a single pictorial representation of a design solution and that flexibility and innovation can be enhanced through the pictorial representation of multiple and diverse solutions to a problem. This is the direction in which our research is currently moving and possibly indicates a way in which intelligent design aids could take advantage of the powerful effects of pictorial representations on design problem solving.

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Appendix A: Instructions for Control Group

DESIGN EXERCISE

Around 90 per cent of elderly people live at home and wish to maintain their independent lifestyle for as long as possible. However, part of the natural ageing process is a reduction in muscle strength and sensory perception, and this can interfere with the ability to perform daily tasks at home. For example, for some elderly people, one of the difficulties in bathing independently is getting down into the bath and back up again. Many people who show a high level of general function and mobility in the home could still require assistance with this particular activity. This is an especially difficult action as it involves considerable strength and balance. When the person becomes unstable during a bath transfer, there is a high risk of injury from a fall.

The aim of this exercise is to design a device to assist elderly people in getting in and out of the bath, without the need for assistance from other people. The device you design should meet the following requirements:

* safe
* easy to use
* portable and/or storable
* attractive
* easy to clean and maintain

Detailed and accurate drawings are not required. Simple, rough outline sketches are all that is needed. The sketches may be annotated with written comments to clarify your intentions.

You will be allowed 45 minutes to complete the design. If you wish you may complete more than one design. Please number each individual design.

Appendix B: Instructions for Experimental Group

DESIGN EXERCISE

Around 90 per cent of elderly people live at home and wish to maintain their independent lifestyle for as long as possible. However, part of the natural ageing process is a reduction in muscle strength and sensory perception, and this can interfere with the ability to perform daily tasks at home. For example, for some elderly people, one of the difficulties in bathing independently is getting down into the bath and back up again. Many people who show a high level of general function and mobility in the home could still require assistance with this particular activity. This is an especially difficult action as it involves considerable strength and balance. When the person becomes unstable during a bath transfer, there is a high risk of injury from a fall.

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* safe
* easy to use
* portable and/or storable
* attractive
* easy to clean and maintain

Detailed and accurate drawings are not required. Simple, rough outline sketches are all that is needed. The sketches may be annotated with written comments to clarify your intentions. See Figure 1 (on separate page) for an example of the level of detail required.

You will be allowed 45 minutes to complete the design. If you wish you may complete more than one design. Please number each individual design.