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Towards the capture of design intelligence - a focus on independent learning materials and calculation software for the analysis of structures

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Abstract

Many writers have claimed that designing requires particular ways of knowing, but there has only been limited progress towards identifying what these are. This paper explores one area of design pedagogy: technology for design and, in particular, the interaction of the creation of form and structural analysis. Prior work concerning architectural students is noted and the approach adopted to making order-of-magnitude estimates with Industrial Design and Technology undergraduates at Loughborough University is discussed. A transparent 'system' involving text-based flexible learning materials and calculation software has been developed and trialled.

The materials were used by 118 students in 1995/96 and 116 students in 1996/97 with a total teaching contact time in the Foundation Technology module of 17 hours. Feedback was obtained by analysing the students' performances on a Foundation Technology assignment, from the subsequent design practice activity and from questionnaires. The feedback was supportive of the judgements made concerning the required foundation studies and the flexible learning approach. Its success points the way forward towards a more encoded system.

In the 1980s expert systems were seen as offering great potential to enhance the capability of designers through the capture of aspects of design intelligence. The author's views on this potential were published in 1987¹. Such potential undoubtedly existed, and still does, but, then as now, progress is limited by our understanding of the knowledge, skills and values a designer exploits in design decision-making.

The general issues associated with identifying the nature of design intelligence were discussed in a paper by Cross². In particular, her paper focused on one of the criteria identified by Gardner³ for assessing claims concerning a particular competence or intelligence, namely: 'susceptibility to encoding and decoding in a public symbol system' (p.15). Her paper reviews research relating to the roles of the left and right hemispheres of the brain in the acquisition and use of codes. In referring to the work of Goldberg *et al*⁴ she writes:

This hypothesis proposes a right-to-left shift of hemispheric dominance (or

cognitive style) in learning processes associated with the acquisition of new codes or language systems. This shift was demonstrated by professionals showing greater left hemispheric activity in a given task and novices showing greater right hemispheric activity on the same task. The implication drawn was that the two groups, 'professional' and 'novices' demonstrated differential command of certain cognitive skills and codes on the same task. (p.16)

Thus, novices tend to engage in greater right hemispheric activity in order to identify an appropriate code or symbol system. Professionals tend to show greater left hemispheric activity which 'may be associated with the use of any well routinised code'² (p.16). This paper seeks to extend this discussion in relation to an area of design pedagogy - technology for design and, in particular, the analysis of structures. This area of technology is not normally initially recognised as important by industrial design students. Materials and processes is recognised as essential⁵, but the analysis of

structures is thought to be of marginal significance - despite the reality that such analysis can be the fundamental determinant of form.

In describing his approach to developing competence in structural analysis for architects Howard describes a hierarchical approach⁶. Three stages are identified: understanding the behaviour of a structure in qualitative terms; learning to make calculations for simple structural elements; and finally a holistic 'review'/approach.

He must now climb to a third level, one on which he considers the structure of a building as a complete entity and sees how it is related to the total architectural effort. (p.6)

Howard's book describes a number of case studies intended to help students to reach this third level. Yeomans echoes Howard's approach in discussing his teaching of structures to architectural students. He seeks to develop qualitative understanding through an exercise in which students are asked to select a building from a given list and to make a model to illustrate its structure⁷. He comments as follows:

In teaching engineers the usual practice is to present students with a set of analytical techniques.... In contrast, the teaching of architects has always been based on developing design skills. Analytical techniques are taught so that students may have the tools by which to 'prove' the validity of their design proposals but this leaves the students with little guidance on how the structural forms are developed. Without this the student may be left with an extremely inefficient design process based on little more than trial and error... We should be aiming to develop in the student a feeling for these technical possibilities, enabling him or her to handle them imaginatively in design. (p.139)

Hence, from this prior work concerning architectural students, the essential nature of an appropriate pedagogical approach to

structural analysis for designers can be identified. Namely, students should progress from the development of a qualitative understanding of structural elements, through the development of competence in calculation procedures to a holistic approach to the design of structural forms.

What can be said concerning the requirements for industrial designers? The Myerson report in 1991⁸ concerning technological change and industrial design education recommended that:

.... courses should endeavour to develop in students an ability to calculate order-of-magnitude estimates about, for example, load-bearing capacity of structures or strength of materials;

It is actually essential for industrial designers to make such estimates if they are to consider such matters as the weight of a product, the balance of a tool, the stability of a free-standing form, the cost or even the manufacturing route. Decisions on these matters require some knowledge of the approximate size of the components and, if they are load-bearing, this means some form of structural analysis. Of course, industrial designers, like architects, are dealing with ill-defined problems, in that they are engaged in defining forms not just in analysing their suitability. Hence, industrial designers are dealing with problems in the same general category as architects, but there will be differences in detail associated with the different product classes.

Given that the appropriate approach and detailed content have been identified there is another equally problematic obstacle to aspirations concerning the development of structural analysis 'expert systems' for designers. The real hope is that designers will be able to access such capability 'at the point of need'. Designers expect to have learnt some knowledge, skills and values through foundation studies and to acquire others for particular projects. There is, of course, the option of consulting an expert in the required area (as architects have always done in working closely with structural engineers). An 'expert system' might legitimately address

either of these alternatives, that is new learning by the designer or replacing the consultation process - but any success depends not only on the creation of the system, but also facilitating its use. This could engage the system analyst in a number of areas just as poorly understood as design intelligence: for example, the assessment of prior learning, the user's independent learning skills, the selection of appropriate media, the balance of 'user' and system control and the appropriate level of transparency. This is not an exhaustive list, but enough to indicate that even an expert system which accurately represented the required knowledge, skills and values would not necessarily be successful.

The Myerson report also noted that:

There is strong evidence to suggest that the best results in the teaching of technological subjects by engineering and science staff are achieved when:

engineering specialists reorganise their material and rethink their delivery in response to a course team 'brief' to suit the particular needs of ID (industrial design) students; (p.44)

As an engineering specialist the author pursued exactly this approach. It was decided that the initial 'system' would be fully transparent and in the users' control: it would take the form of independent learning materials and computer software. The emphasis was on removing the need to be capable of carrying out complex calculation procedures and, hence, to help the students through the second level identified by Howard. The software used was written by Prof. S.A.Urry and listings were published in *Advanced Design and Technology*⁹. The author was also aware of many issues relating to flexible learning strategies from previous research¹⁰.

Presented in this way both the methodology and calculation procedures are transparent to the students. They are thus able to investigate either of these matters at a depth they choose. If the whole package had been encapsulated

within an expert system its transparency would have been lost, with a consequential loss in its value for teaching and learning.

Feedback was sought in three ways:

- by analysing the students' performances on a Foundation Technology module assignment;
- by offering troubleshooting sessions in the subsequent design practice project;
- by asking the students to suggest improvements after completing their design practice project.

These evaluation strategies provided opportunities to intervene and resolve any difficulties resulting from this initiative.

All the students using the flexible learning materials for the software calculation packages had previously used an inter-semester flexible learning unit on energy. Consequently, the students had already acquired some independent learning skills. The materials were used with all the first year Industrial Design and Technology undergraduates in 1995/96 and 1996/97.

Foundation technology module inputs

In the first semester the students had a brief introduction to mechanics consisting of three, 1 hour lectures and three, 2 hour classes. These covered such concepts as centroids, centres of gravity, forces, moments, graphical and algebraic methods through a product-centred approach. The unit ended with the analysis of a mastic gun (as a product typical of subsequent design practice activity), relating to both its overall performance and a qualitative assessment of the structural elements it contains.

The students were given flexible learning materials on structural analysis at the beginning of the second semester. They had three, 2 hour classes focusing on the development of skill in using the software. The two optional, 1 hour case study lectures (based on a lounge storage system) took place in weeks four and five - midway through the students' learning. Hence, they were not lead lectures, but served as reinforcement and opportunities to seek clarification. The

presentations sought to help students through the right hemispherical activity of internalising an appropriate approach to analysing structures. Thus, the total teaching time related to structural analysis was 17 hours. The students completed a structural analysis coursework assignment for the Foundation Technology module before undertaking the subsequent design practice project, in which it was hoped that their performance would be more 'professional'.

Design practice briefs

The briefs set in 1995/96 were based around 'Temporary Demountable Structures': a shelter for disaster situations; a sales kiosk; a garden hammock; a display structure; and a play structure for children. Some notes were provided by the author concerning key technological issues relating to each of these briefs. In 1996/97 the briefs concerned the design of simple mechanisms e.g. cancrushers, cork pullers, orange juice extractors, paper hole punches etc. The students were required to identify their own product proposal following a product analysis exercise.

Feedback results and conclusions

The evaluation of this initiative must be a continuous activity. In the first year, the

progress of the students through the flexible learning materials was carefully monitored and discussed at the associated practical classes. This revealed only occasional difficulties in understanding particular issues.

Students' performances on the Foundation Technology assignment

In 1995/96 the assignment was assessed in four sections. The first two related to the analysis of the whole structure and the last two to calculation procedures for structural members. A comparison was made of the performances of the 118 students on these sections. In 1996/97 the 116 students were also asked to revisit their initial analysis following the detailed calculations (reflecting the cyclical nature of structural analysis). A summary of the results is shown in Table 1. The earlier aspects are 'rehearsed' in Semester 1, and the results are interpreted as reflecting the time available to internalise the procedures. Comparatively few students coped well with 'revisiting' or taking a holistic view following detailed analysis.

Following assessment and feedback, the 12 students who had failed to submit or performed badly in 1995/96 were interviewed. Two students mentioned illness, the remaining difficulties were caused by time management

	<i>Whole structure calculations e.g. overall dimensions and stability</i>		<i>Calculation procedures for structural elements</i>		<i>Total</i>		<i>Revisiting</i>
	1995/96	1996/97	1995/96	1996/97	1995/96	1996/97	1996/97
Average	67.2	82.5	49.2	39.7	57.6	61.6	32.4
Minimum	0	45	0	0	0	26	0
Maximum	100	100	97	84	94	91	90
Standard deviation	27.4	11.65	32.4	20.3	27.0	13.36	25.44

Table 1 Percentage scores concerning overall structural considerations, calculation procedures and total scores on Foundation Technology assignments for 118 Year 1 undergraduates in

associated with a number of deadlines converging just before Easter. The major request was for the whole pack to be given out at the start of the Spring term, rather than in three sections (as in 1995/96). This had been done to avoid the students feeling overwhelmed, but the greater flexibility offered by having the whole unit was seen as more significant. This was done in 1996/97.

Troubleshooting for design practice

The flexible learning materials only dealt with those elements of structural analysis which were believed to be vital. Inevitably, as the students were designing other issues arose. Consequently, lunchtime seminars were offered (rather than individual consultancy). Three, 1 hour seminars were all that was required to support the 118 students. The topics which were requested were:

- resisting wind loads (centres of pressure);
- analysing extending poles;
- analysing domes;
- approaches to analysing portal frames.

Wind loads were already briefly covered in the learning materials and, as with extending poles and domes, were not regarded as generally relevant enough issues for industrial design students to make additions in 1996/97, but this is under review. They are currently seen as issues for students to deal with on particular projects, rather than part of foundation studies. As portal frames seem to arise frequently, notes were added to the assignment in 1996/97.

Suggested improvements from students

As feedback throughout 1995/96 was essentially supportive, the decision was made to check the validity of the initiative by posing some 'provocative' rather than general questions. Twelve of the students (~10%) replied on a voluntary basis. Table 2 in appendix 2 shows the questionnaire and two students' responses in italics. All twelve responses were very interesting, but these two give the flavour. The first quotation in the questionnaire was from a paper presented at IDATER 96¹¹.

Some students did comment on the need for careful proof-reading, which was justified, but,

in general, they were both supportive of the approach taken and very sharp in identifying the nature of the issues. It can be seen that the students' comments echo the early discussion in this paper.

It was clear that the students were having difficulty making the connection between the foundation studies and the subsequent design practice. Consequently, the decision was taken to alter the nature of the Foundation Technology assignment to be closer to the 'real situation'. One of the design practice tutors sketched a design for an information stand indicating the level of detail that students could expect to have at the appropriate stage for the calculations. Figures 1 and 2, given in appendix 1, show the assignments for 1995/96 and 1996/97 respectively. In 1996/97 the students needed much more help in getting started (which was given), and it remains to be seen whether or not there is a beneficial effect.

Conclusions

This paper discusses an approach which enables industrial design students to successfully tackle order-of-magnitude estimates in structural analysis. It is the result of an engineering specialist spending many years understanding the nature of the particular design activities, identifying appropriate foundation studies and developing appropriate flexible learning materials (The author joined the Department of Design and Technology in 1984). There is more to be learnt, but the issues are now well enough defined to attempt a more encoded structural design 'expert system'.

One of the Design Practice tutors - Clive Mockford - commented as follows:

Students were noticeably more confident in approaching the task than in previous years. They may not have been more successful in terms of design outcomes, nor engaged in more mechanical analysis, but the 'fear factor' seemed to have been reduced. An open minded approach seemed generally evident.

This is difficult to interpret as more professional, but nevertheless a useful result.

Acknowledgements

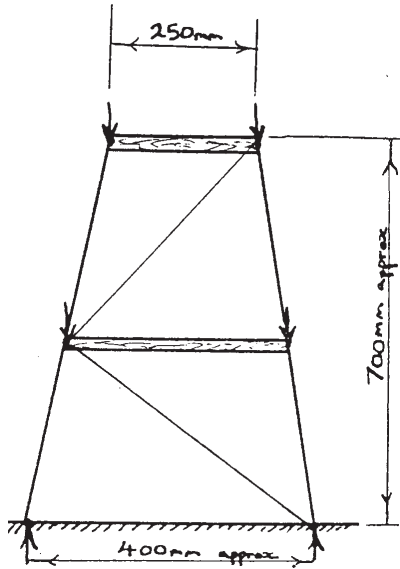
The author is grateful to: Prof. S.A.Urry for both writing the software used for structural calculations and giving permission for its use; Jay Cubitt for her work in co-authoring the flexible learning materials; the Loughborough University EDH School Directorate and Flexible Learning Initiative for funding the work; Paul Wormald and Clive Mockford for facilitating the link to design practice; and to students, both past and present, for their constructive attitudes and support during a long development process.

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Appendix 1

Figure 1 shows the side elevation of a camping frame to be designed to act as a working and storage unit inside tents. The dimensions of typical camping equipment and the associated magnitudes of the loads are also given. You are required to carry out an initial technical feasibility study.



	Dimensions (mm)	Magnitudes (N)
	L X W X D	
Cooker - double burner	450 X 250 X 60	27
Water container	250 X 250 X 200	75
12 Food cans	70 dia. X 120	5 each
Crockery	400 X 250 X 200	38
Cooking pans	400 X 200 X 150	8
	350 X 150 X 120	6
Personal stereo	500 X 100 X 150	40
Gas bottle	300 X 300 X 300	18

Figure 1

Figure 2 shows a drawing of a partially designed display stand for an information booth. No further details are available - you should estimate whatever data you require to complete your analysis. The information booth is to be free-standing.

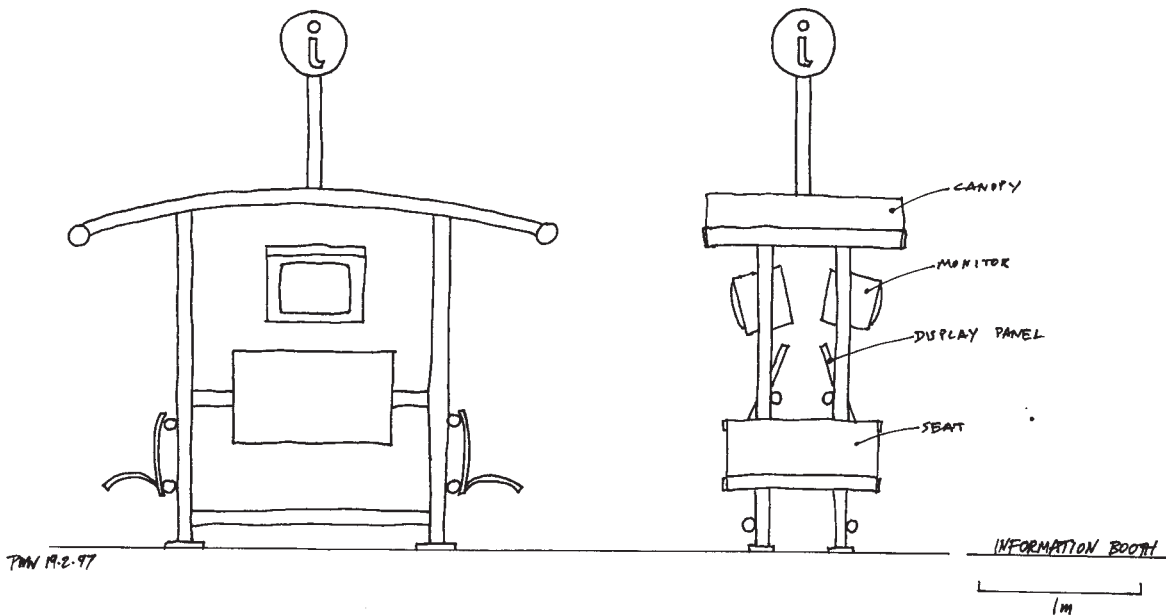


Figure 2

Appendix 2

Table 2 The questionnaire used in 1995/96 and two students', *I and II*, responses

LOUGHBOROUGH UNIVERSITY
DEPARTMENT OF DESIGN AND TECHNOLOGY

1995/96 Structural Analysis Questionnaire

Name: _____ (not essential, but it would enable me to follow up issues if I do not immediately understand your comments).

1. The following quotation is taken from a recent research paper.

The industrial designer, working mainly with small components or electrical equipment told us:

Without fundamental knowledge of materials you won't have any understanding ... without the ability to determine when something's going to break ... you're not going to be able to design many types of brackets, although it has to be said that I don't sit down and do a set of calculations for every bracket I design because more often than not the amount of load your applying is so small you don't need to do that, but that's down to experience and knowledge and at least I have the ability to do the calculations if I need to.

What do you think about this viewpoint?

(I)I feel that it is good to have the ability to do calculations when considering a new design. Sometimes they may not be needed, but you can assure yourself that you can do them if required. If you are unable to do advanced calculations then design ideas may be restricted. If the skills learnt are used at least once then in my mind they were worth learning.

(II) As a designer it is my opinion that a knowledge of materials is important. It is clear from work in the first year that components often need not be as large or strong *as one may think from first impressions. Therefore it would seem to me to be important to design for the minimum amount of material if possible.*

2. The Myerson Report concerning Technological change and industrial design education (1991) recommended as follows:

Additionally, course teams should pay attention to the following aspects of course content:

- courses should endeavour to develop in students an ability to calculate order-of-magnitude estimates about for example, load-bearing capacity of structures or strength of materials;

The new 'structural analysis' flexible learning materials (sections A, B and C) together with associated classes and lectures on a case study (the lounge storage unit) were developed to try to meet this need.

continued

Table 2 (continued) The questionnaire used in 1995/96 and two students', *I and II*, responses

How well did they succeed? How could this strategy be improved?

(I) Sections A, B and C, for me worked well as I could do and learn them in my own time. The lectures set the ball rolling and from there I was able to finish each section working through the necessary examples. I can't think of any improvements that could be made as I found them OK to use.

(II) The sections and project definitely made me more aware of these principles and the ability we have to calculate them. Further work will be necessary to reinforce this and give us a genuine ability to adapt the basics that we have learnt. With the sections A, B and C it was possible to work through using the examples given. However applying them to the project then was much harder as they were needed at the same time.

3. Design education is normally approached through the concept of foundation studies and subsequent related project work. The structural analysis component of foundation technology should have provided an adequate foundation for the projects set in year 1 design practice.

Did it? Should other matters have been considered? Can you give any examples?

(I) The structural analysis work was helpful but when it came to using it in design practice I found that I was limited to what I could design and apply foundation work to. I feel that this will always be a problem as there would be too much work to cover every aspect of structures. An individual problem rather than a common one.

(II) The foundation technology did provide knowledge for the design practice. However, it was sometimes difficult to apply directly to the project. It would though be impossible to provide examples for the range of projects that people decided on.

4. One of the hopes of using flexible learning materials was that they would provide a ready source of support if the need arose when completing the subsequent design practice project. It should also have allowed you to progress at your own speed, when initially working through the materials.

Did the flexible learning approach - rather than more lectures, for example - help you?

(I) For me this way of learning was much better because if I happen to have a bad day and I find it hard to concentrate in lectures then all that has been said has not been learnt. I could do this learning in my own time without outside pressure.

(II) ... The flexible learning was a good system and definitely helped me more than lectures as it was clear and correctly ordered and available for consulting when and where necessary. Relevant info for a project might not be planned for a lecture for weeks.