RP VS WORKSHOP: HOW MODELLING METHODS AFFECT EARLY DESIGN DEVELOPMENT

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ABSTRACT

The use of physical modelling has long been established as a crucial part of the Product Design process. In recent years Rapid Prototyping (RP) has played an increasingly important role in this area, within industry and education. But exactly how RP fits within a modern Product Design curriculum, and the extent to which it is utilised, are contentious issues. While some Universities are happy to make use of RP throughout the design process, to date Bournemouth University (BU) has favoured traditional model making skills during the concept testing stage. However, while traditional methods may present a number of advantages over RP – such as more direct scalar and tactile feedback, and a broader understanding of materials – they may also have a detrimental effect on students' designs. The limitations of producing an accurate model by hand may well be responsible for restricting design development, while the use of new technology may instead encourage a wider range of possibilities.

This paper seeks to explore the influence of RP and traditional workshop skills during the concept modelling phase of Product Design. Through the use of a comparative study involving design iterations with different modelling methods, the early design process is examined with particular focus on the experiences of the students themselves. The results highlight the benefits and drawbacks of using RP during concept testing and how new technology can influence student behaviour at this crucial stage of design development.

Keywords: Rapid prototyping, product design, foam modelling

1 INTRODUCTION

Despite the technological advances of the past fifty years physical models still fulfil an important role within Product Design. Whilst CAD software has developed to provide increasingly realistic renderings and analysis of virtual models, the physical model delivers a whole range of immediate scalar and tactile feedback, as well as offering a valuable tool for demonstration, evaluation and marketing purposes.

At Bournemouth University (BU) model making forms an important part of the BA/BSc Product Design course. During the three years while they are present at the University, students are timetabled for around 530 hours within the prototyping workshops. As well as producing a number of fully working prototypes, students are encouraged to use models throughout the design process to evaluate and refine their designs. These models and prototypes have tended to be almost entirely produced using traditional model making and engineering skills, despite the University owning a number of RP machines, including a Stratasys Titan Fused Deposition Modelling (FDM) unit capable of producing high quality ABS items. The course's emphasis on encouraging traditional skills has meant that this equipment was only utilised for final prototype parts that were impossible or too time-consuming to make via other means. Consequently less than half of the students would gain experience in RP, and then only as a prototyping shortcut rather than as an integrated part of the design process.

This heavily restricted use of the facility represents not only an ineffective use of resources but also a wasted opportunity for educating students in the variety of uses of a tool that is increasingly considered revolutionary for the future of design and manufacture. The rapid worldwide expansion of additive technologies in recent years, not only within education and industry but now in the home, is clear and 3D printing continues to demonstrate its usefulness in all phases of the design process. An investigation was therefore carried out into the potential ramifications of extending RP into other areas of the Product Design (PD) course.

2 LITERATURE REVIEW

Much has been written about the practical consequences of having a rapid prototyping facility. The savings in workshop manpower, equipment and space have been weighed against the expense of investment in RP equipment. Material costs have been compared and build times have been analysed. The considerable health and safety advantages of additive technology have been championed.

However, worthy though these considerations are the concerns at BU related more to the educational experience of the Product Design students themselves and whether RP could be used to aid their development as Designers. A considerable amount of literature has featured RP in design courses around the world over the past twenty years, but a large proportion of it focussed on the potential of the new technology rather than presenting evidence of the results of its use [1][2][3]. This literature, in common with most of the popular media coverage surrounding RP, tends to be notably positive and optimistic about the introduction of additive technology, though it is usually accompanied by little or no supporting evidence.

Although evidence-based research studies might be expected to offer a more balanced view, the literature from courses which have replaced traditional model making with RP tends to be similarly skewed in favour of the benefits of rapid prototyping. However Helbling and Traub's 2008 study [4] highlights many valid issues, perhaps most importantly the complexity of form that additive technology can reproduce, therefore ensuring that designs are "no longer hindered by manufacturing difficulty". This view was echoed in a slightly different way by Flowers and Moniz [5]: "Some prototypes may be ingenious solutions to a problem, but building them could go beyond the capabilities of students and their equipment." This raises the complex and important issue of the relationship between the student's intended design, the model and the method of manufacture.

In 2010 Forkes [6] noted the discrepancy that often occurs between design drawing and model due to a shortage of skills on behalf of the student. This appears obvious: RP models will always be more faithful representations of the original CAD drawing (though not necessarily the designer's vision) than hand-made models. However it is also possible that the standard of design work produced via CAD/RP is genuinely higher, irrespective of the quality of the model. In 2006 Wilgeroth and Gill [7] claimed that the adoption of RP, in the form of CNC, at University of Wales Institute Cardiff had eliminated the phenomenon of "design for model making" - where students purposely produce designs that they are likely to find easier to prototype - although supporting evidence was lacking.

2.1 Comparative studies

Comparative studies looking at whether RP and traditional model making lead to different student experiences are more scarce. However Greenhalgh's 2009 study [8] of Utah State University Interior Design students, while drawing few conclusions, raises many interesting questions. Assessing the differences between two small groups simultaneously designing a chair with RP and traditional methods, a number of interesting suggestions are made:

- That RP can level the playing field for designers of differing model making ability.
- That RP can more easily enable quick revisions to be made to designs.
- That traditional model making restricts and simplifies a designer's initial ideas, while RP has the opposite effect of extending and "magnifying" the original concept.

These ideas echo the claims of other researchers [5] [6] [7], but particularly intriguing is the possibility that, by encouraging students to "test the capabilities", RP pushes students to explore options that may have been discounted – or not even considered – at the beginning of the design process.

The early stages of product design are vitally important, and models can perform a crucial role in early design development. It is possible that RP may be able to play a part in these earlier stages of product design development and may bring considerable creative benefits.

A comparative study was therefore devised, focussing exclusively on PD students, to explore the influences of both RP and traditional workshop skills during the concept modelling phase. Five key areas were selected for particular attention:

- Whether 'design for model making' exists for RP.
- How modelling methods affect design development.
- At what stage RP should be introduced into the design process.
- Whether students find traditional model making or RP limiting or liberating.
- Which method the students feel contributes most to a successful design.

3 STUDY METHODOLOGY

Second year PD students at BU currently undertake a 20-credit Design Visualisation unit, consisting of two consecutive 10-week elements, each running for two hours per week. The first element covers 3D CAD modelling and rendering; the second – taught by the author – covers physical concept modelling in the workshop. This second half of the unit offered an ideal opportunity to conduct a comparative study with minimal disruption while still maintaining relevant educational content for the students. As well as introducing students to RP at an earlier stage in their studies, it would also offer a useful link to the 3D CAD modelling element undertaken in the first half of the unit.

For ethical reasons, and to allow comparisons to be made by the students themselves, it was important that the entire group experienced both RP and traditional model making. This presented a problem in deciding which method should be used first. Running the RP exercise prior to the workshop exercise could well elicit different responses to running the RP exercise after the workshop exercise. However this also presented an opportunity to explore the relationship further: by dividing the group in two and running the exercises in different orders for each group, both sets of students would be able to contribute, offering different but complementary viewpoints.

The students were therefore instructed, on completing the first, CAD-based half of the unit, to prepare concept sketches for a laptop computer mouse. During the first week of the second half of the unit one group was asked to create their design using SolidWorks CAD software while the other group used Styrofoam and urethane foam. In week three - allowing a period to RP the CAD models - the two groups were asked to swap methods, developing and refining their designs if necessary.

3.1 Epistemology

The majority of the studies conducted into the use of RP in design education have been based on a positivist approach. In some cases this approach has been justified: in determining the allocation of time or resources it is possible to apply quantitative techniques and obtain valid and specific results. However, when exploring elements such as frustration, enjoyment and influences, this approach produces "research with human respondents that ignores their humanness", in the words of Lincoln and Guba [9]. Therefore a predominantly interpretative epistemology was employed, in order to generate the rich data required to investigate complex matters such as creativity and motivation, and to allow greater scope to pursue the relevant issues in a more flexible way as they arose during the research.

Focus group discussions took place to gather the bulk of the rich data required, and prior to these a questionnaire was issued to all the volunteers in the study. Although over-detailed quantitative analysis of the responses would be inappropriate, the questionnaire was extremely useful in identifying general trends and opinions. Furthermore, the provision of a large number of free text options within the questionnaire helped to raise issues previously not considered, as well as providing further comment and improving the validity of the data.

4 RESULTS

A total of 42 students agreed to participate in the study, all of whom completed the assignment by producing initial concept sketches, a printable CAD model and at least one foam model. 30 students returned completed questionnaires, and 13 of these students also engaged in the focus group discussions.

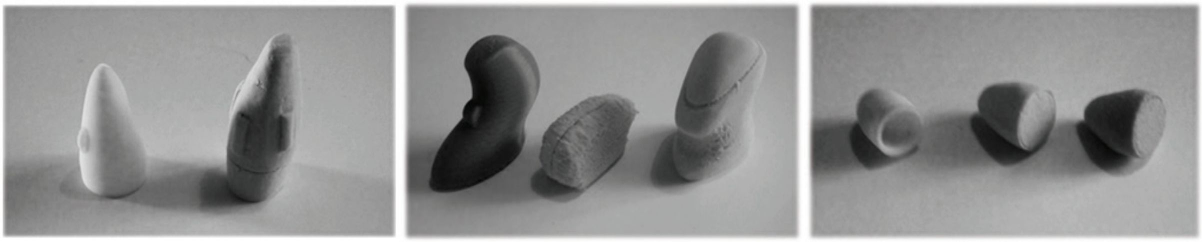
The questionnaire and focus group questions were specifically designed to focus on the five core issues previously identified, and the results were as follows.

4.1 Design for model making

What is particularly evident is the acknowledgement by the students that advance knowledge or consideration of the modelling method did indeed influence their concept drawings. 72% of the students admitted that the knowledge that they would have to create a physical model influenced their initial design. For traditional modelling the most commonly cited reasons were because of limitations imposed by available materials, processes and time-scales, rather than because of a lack of modelling skills. Moreover, students confirmed in discussions that this behaviour is not confined solely to this project: "Whenever we've been designing…we kind of develop our designs into something that we know that we can make."

Crucially, the group who produced their RP models first (from here on referred to as group A) were

slightly more likely to admit to ‘design for model making’ than those who produced their foam model first (group B). Unlike the traditional models, which were typically “kept simple” irrespective of modelling ability, the RP models were influenced in different ways according to the student’s ability with CAD. Those with lower skill levels professed to keeping their designs simple, while some of the more advanced practitioners purposely created more complex designs to take advantage of the abilities of additive technology. In addition, the software tool options played a part, by encouraging students to design extruded shapes and regular curves, for example.
Further striking evidence of the effects of advance knowledge was provided by the models themselves. Group A were much more likely to produce ‘radical’ design concepts, with almost three times as many models with non-traditional mouse shapes than group B (Figures 1, 2 & 3).



Figures 1, 2 & 3. Examples of non-traditional mouse shapes produced by group A

4.2 How modelling methods affect design development

Both groups reported a high number of alterations to their designs in first transforming their concept drawings into a three-dimensional object. Significantly, the majority of these changes appeared to be relatively cosmetic for group A, working with CAD while group B, working with foam, documented changes that were primarily concerned with ergonomic issues.
In part this explains the divergence in results concerning intentional design changes when modelling methods were swapped. While just over half of group B made changes in converting their models from foam to RP (Figure 4), over 80% of group A were still making intentional design changes in converting from RP to foam (Figure 5). The majority of the changes noted by group A were issues of ergonomics and scale - “Moved buttons and finger positions”; “Made the height smaller” – reflecting the obvious problems in gauging such issues accurately in a virtual environment. By contrast, group B seem to have resolved the majority of the design issues in foam before moving on to CAD.

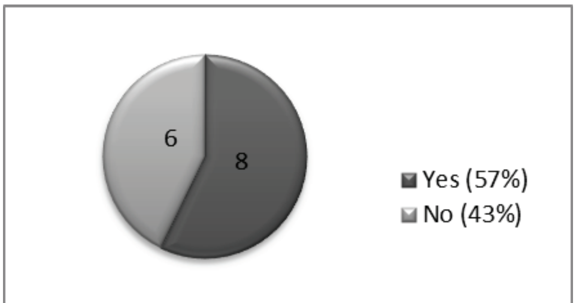


Figure 4. Design changes for 2nd model (group B)

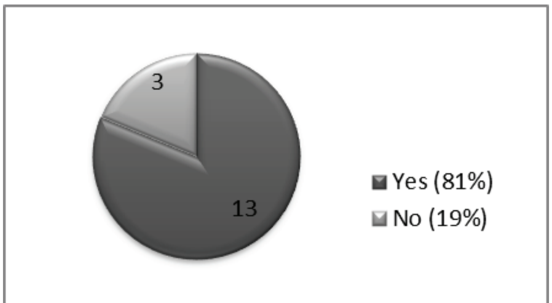


Figure 5. Design changes for 2nd model (group A)

The rapid turnaround and instant physical feedback of working with foam inevitably played a part too by speeding up design iterations. Although roughly the same amount of time was spent producing the CAD model and foam model, over 70% of students were able to produce two or more models, with some producing four or more.
As well as intentional design changes, group A reported a high incidence (44%) of unintentional design changes. It was evident that many of the designs first produced via RP had developed in such a way that made them difficult to reproduce in foam “because on SolidWorks I can do what I want, while on blue foam you’re limited with the tools”.
The phenomenon of ‘accidental design’ was also observed on several occasions with students working in foam: “The first design I had, the off-cuts from it were better than the original one. So I ended up just playing with them and they worked out better.” The students agreed that this was something unlikely to occur with RP.

4.3 At what stage is RP most effective?

One of the clearest results from both the questionnaire and the focus group discussions is the general consensus amongst the students that rapid prototyping is particularly useful towards the end of the concept modelling phase. The main reason given for this is the ability to reproduce faithful variations of the design once most of the major design work has been accomplished, but it was also noted that – in this instance – RP represented the intended material of manufacture more successfully. It was also generally agreed that the RP model looked "more professional".

With regard to the earlier use of RP the vast majority of both group A and B agreed that foam modelling was better to start with than CAD, as it enabled quick resolution of ergonomics and scale, and was generally better suited to the 'fuzzy front end' of a project.

However it is worth noting that some students argued forcefully that early use of CAD had been extremely valuable in helping to develop their designs, and it is plain to see that these designs would have developed very differently – and arguably less successfully – if foam had been used first.

4.4 Limiting or liberating?

The students' attitude towards foam modelling was clearly dependant on whether they had modelled their design in CAD first. While 64% of group B found foam modelling fairly or very liberating, the corresponding figure for group A was only 32% (Figure 6). These results appear to tie in with the theory that at least some of the designs modelled in CAD had developed in a way which made them difficult to model by hand.

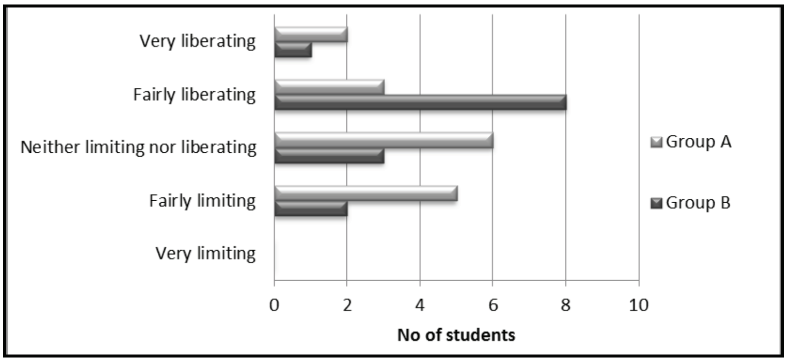


Figure 6. Foam modelling: limiting or liberating?

Comments about foam modelling, while mainly positive, reveal the often ambivalent attitude towards the process: "More satisfying [than RP] but frustrating at the same time. I feel more proud of the foam model". One of the particular frustrations voiced about working with foam was the difficulty in going back on errors or experiments in shape: "You can experiment more with CAD, and go back and forwards to get what you want. But with hand [modelling], once you've gone too far that's it".

RP was less divisive in terms of whether it was found limiting. Only five of the thirty students questioned found it 'fairly limiting', and none found the process 'very limiting'. There was a clear difference of opinion, however, on whether RP stifles or spurs creativity, and again this was linked to skill level. One student less confident with CAD claimed, "You can't really design something creative on SolidWorks"; another, who described himself as a CAD expert, claimed that it "opens up a lot of doors when it comes to creativity".

The creative limitations of the software itself were also noted. Some students referred to the level of freeform subtlety that can be applied in hand modelling, and the frustration with the difficulty in applying similar subtle changes to virtual models.

4.4 Foam or RP – or both?

It would not be unreasonable to expect that a design would 'improve' as it developed, and in the case of group B this is reflected in the fact that a clear majority, 64%, expressed a preference for their final model, the RP version. However in the case of group A only 40% chose their final, foam, model, with slightly more preferring their earlier RP version.

This would seem to provide further support for the view that some of the CAD models of group A had developed in a way that was subsequently difficult to model in foam. Despite this, it is important to stress that not one of the students expressed an opinion that the foam modelling had been unhelpful or

a waste of time, even amongst those who felt the RP version presented the most successful design.
The usefulness of both methods – and support for the use of an iterative process in concept modelling - is expressed by the fact that every single student rated their first model – whether foam or RP – as ‘fairly useful’ or ‘very useful’, with over three-quarters selecting the latter.
There was overwhelming evidence that both types of modelling were felt to be important for successful concept design development. None of the students expressed a view that CAD or foam alone would have produced equally successful results, and most were vocal in their support for mixed modelling: “Both the RP and foam model helped when designing. They each play a part and have their own positive and negative aspects but should be used together”.

5 CONCLUSIONS

The evidence obtained clearly points to the widespread existence of “design for model making”, not just during this project, but across most – if not all – of the projects on the PD course where students knew they would be expected to produce a model of some kind. In the majority of cases this resulted in producing a simple concept that could be easily manufactured within the timescale. Most importantly, the knowledge that the model would be produced via RP did not prevent design for model making occurring, though – in contrast to traditional modelling – the students who were more skilled at CAD tended to use the opportunity to complicate rather than simplify their concepts. These findings run contrary to the claims of previous researchers [9].
The perceived wisdom, including that of the students themselves, is that it is most beneficial to undertake foam modelling prior to RP. However, many of the students on this project achieved great success – and tended to produce more ambitious designs – by using RP first before moving on to foam. What is certain is that the order of modelling methods makes a difference to the final design: it seems unlikely that the designs would have developed in the same way had the order of processes been reversed.
By introducing students to RP at an earlier stage in product development, they gained a lot of important knowledge about how this technology can be used effectively, as well as the potential drawbacks. Even those students who produced more ‘RP-friendly’ designs conceded that working in foam was a vital part of the design process. Both RP and traditional model making clearly have something to offer, and on this project both processes were judged equally necessary to maximise the potential of the design.
Most importantly for Bournemouth University, the experiment was viewed as a great success by staff and students alike, and a valuable addition to the PD course.

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