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# UNDERGRADUATE DESIGN AND MAKE ACTIVITY

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**ABSTRACT**
An investigation into how universities deliver Design and Make activities to engineering students has been undertaken, by paying particular attention to the design brief and the extent to which students manufacture their own designs. Developing practical skills is a requirement for accredited degree courses, however, developing such skills requires machine tools, time and workshop space. Two types of design brief have been identified between the University of Bath and six other universities. The organization of the Make is shown to vary in location, duration and timing, therefore, yielding different levels of impact on the teaching timetable.

*Keywords: CAD, undergraduate, design, prototype*

## 1 INTRODUCTION

This paper is based on the Design and Make activity which runs over the first two years of six engineering undergraduate courses (Mechanical, Aerospace, Automotive, Integrated Mechanical and Electrical, Manufacturing, and Advanced Design and Innovation). The courses have a virtually common timetable in the first two years and the activity is delivered in the context of large student numbers, limited machine tool resources, time to manufacture in the workshop and student experience, group working, information development and control, engineering drawings and assessment.

The UK Quality Assurance Agency for Higher Education (QAA) has since 2006 adopted the standards in UK-SPEC as the subject benchmark statement for engineering. Under the UK-SPEC's requirements for the Accreditation of Higher Education Programmes [1], degrees should deliver Engineering Practice as one of the Specific Learning Outcomes which provide students with an '*ability to apply engineering techniques*'. Furthermore, specific reference is made to practical engineering skills acquired through laboratories and workshops. The Design and Make activity has been, therefore, steered towards machine shop manufacture by the students of their prototypes.

Since the publication of Standards and Routes To Registration (SARTOR) by the Engineering Council, accredited courses needed to satisfy the Engineering Application requirement, which had originated in the 1980 Finniston Report in the form of EA1 and EA2 primarily to '…ensure that engineering was taught as a vocational subject, from the basis of real applications…' [2]. An Engineering Application laboratory during Year 1 at the University of Bath gives all students hands-on experience of traditional machining processes and serves to underpin the Make phase. However, accredited courses at other universities may not always require students to fully apply those manual skills from EA1 to a Make exercise as well, but develop practical skills through supplementary course-related artefacts, which groups of students dismantle and reassemble [3].

The Design and Make activity requires students to follow the design process from the conceptual phase to the creation of both part and assembly CAD drawings in the last term of the first year, through to the manufacture of a working prototype, in the first term of the second year. The Department of Mechanical Engineering has recently invested in a new Model Workshop, which provides a manufacturing area for students to produce their prototypes. However, student numbers have continued to grow and consideration of whether the approach adopted by the University of Bath is best for the future has prompted a comparison of practice with that at six other similar universities. The information was gathered from telephone interviews and email responses.

## 2 DESIGN AND MAKE AT THE UNIVERSITY OF BATH

This will be considered by a review of both the Make phase and the EA1 workshop programme over the last fifteen years, and an illustration of the current Design and Make process.

### 2.1 Historical view of the Make phase

The extent to which students are able to manufacture and assemble their prototypes will largely depend upon the time allocated, their practical skills developed during the EA1 programme delivery and the resources available. The EA1 workshop programme, which develops students' manual machine tool skills, is a separate exercise to the Make and delivered before the Design and Make activity commences in Term 1 of Year 1. However, the time provided for these will have a direct impact on the timetable which is common to all degree programmes in the first two years. An insight into how the timings and structures of both the Make and EA1 have changed over the past fifteen years is depicted in Table 1.

| Year | Time to Produce Prototype ? | When? (Prototype) | Where? (Prototype) | Workshop programme (EA1) |
|---|---|---|---|---|
| 2009 | 2 afternoons + bookable slots | Yr 2, Term 1 | Dept of Mech Eng, Model Workshop | Dept of Mech Eng, Model Workshop, Y1 (Car) |
| 2007 | 4 afternoons | Yr 2, Term 1 | U of B – various workshops | Dept of Mech Eng in various machine shops, Yr1 (Desk tidy) |
| 2001 | 1 week full-time | Yr2, Term 1 first two weeks (two groups) | U of B – various workshops | Dept of Mech Eng in various machine shops (Desk tidy) |
| 1998 | 1 week full-time | Yr2, Term 1 first two weeks (2 groups) | U of B – various workshops | Dept of Mech Eng in various machine shops |
| 1995 | 1 wk full-time | Yr1 Term 2 end of summer & Yr2 start of Term1 (2 groups) | Bath City College | Yr1, Term2. Bath City College 7-9pm one evening per week. |

*Table 1. University of Bath workshop timetable for Make and Year 1 workshop programme*

Two important observations can be made: one is the reduction in time the student groups have to manufacture and assemble their prototypes and the other is the change in delivery mode of EA1 from Bath City College to the Department of Mechanical Engineering. Now the Department of Mechanical Engineering is delivering the entire process, an increasing demand is placed on the technician staff and workshop facility. The weight of expectation has increased further as enrolments have grown from 136 in 1997 to 240 in the current year on the MEng programmes, necessitating efficient management of the preferred single workspace, the new Model Workshop.

The Model Workshop is smaller than the combined machine tool facilities across the Department of Mechanical Engineering and will be close to capacity during the 2011 Year 2 Make activity with the current cohort. However, the decision was made to use it for both the EA1 Car exercise and the manufacture of the Design and Make prototype to enable students to benefit from modern traditional machine tools and familiarity of setup and operation.

### 2.2 Design and Make activity at the University of Bath

The current structure of the Design and Make activity across the two academic years can be seen in Figure 1, which also gives an indication to some of the inputs and outputs at various points through the process. This linear approach is similar to the design core of the total design activity [4] and represents a simple sequence by which students may be guided. For teaching purposes the model works well because students can relate to the phases of the linear model and more easily understand how a design cycle may be achieved by them.

The Design and Make process starts with a brief which outlines the problem and provides a starting point for the specification which is developed through Question and Answer sessions.

During the Design Development phase, students are required to consider the materials on the Resource List and processes available within the Model Workshop when designing their parts. This presents them with many decisions to make, typical of real-life, and gives them first-hand experience of embodiment design [6]. An important output of this phase is the order form which will be removed from their submitted reports and given to a technician for ordering and preparing *all* the parts and materials over the summer holiday. It is essential for the completion of the prototype in the nominal time of two afternoons that students detail parts which can be easily made by the group of six members using their practical skills developed in EA1. During these afternoon slots, technicians are on-hand to advise and support the manufacture, but not produce, and, if needed, additional slots may be booked to complete the prototypes.

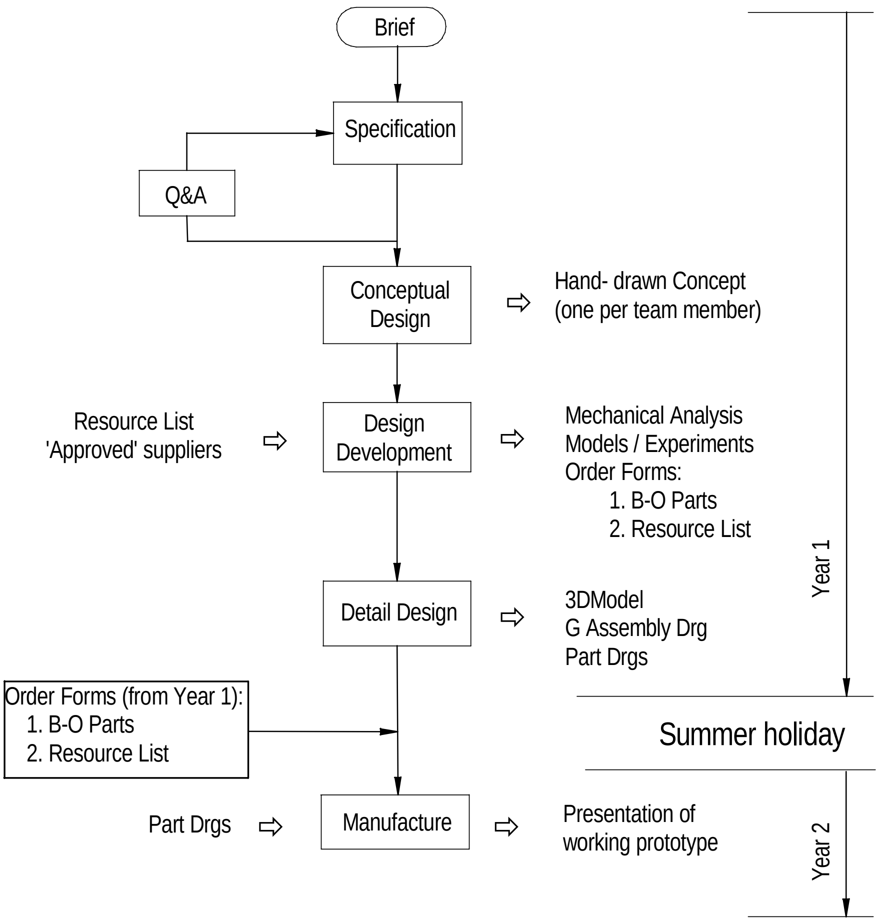


*Figure 1. Design and Make process*

In previous years, technicians did manufacture selected parts, but this was deemed to detract from students learning from their mistakes, chiefly from unsuitable or incomplete engineering drawings. It has become very important, now that students design and make everything, for the exercises to be not only challenging, but achievable in the time given.

The design Brief represents a challenge in that no restriction is placed on the solution and it is for students to decide on a method or principle. This has been broadly classified by Pahl as *novelty design* [5]. Each year the brief is changed and previous examples include a table tennis ball launcher (with feeder), handheld can crusher and shuttlecock launcher (with feeder).

## 3 DESIGN AND MAKE AT OTHER UNIVERSITIES

A survey of universities offering similar undergraduate programmes was undertaken to compare how their Design and Make activity is delivered. In Table 1 is data from universities pertinent to their

*Table 2. Comparison of Design and Make*

| University | Cohort size (2009) | Time for design (Design) | Time to produce prototype (Make) | Exercise |
|---|---|---|---|---|
| A | ~110 | 7 wks x 3 hrs, Y1 S2. Drg output: engineering part drgs & GA | 1 wk (40 hrs) following-on in exam period (wk8) | 'Modular' (vending machine- repeated brief) Electro-mechanical: sensors, microcontroller |

| | | | | |
|---|---|---|---|---|
| B | ~170 | 11 wks Yr1 T1 (Drgs are mainly in sketch form as BS8888 taught next term.CAD ) | 1.5 weeks full-time, Yr1 S1 in exam period | Modular (buggy for mechanical and glider for aerospace -repeated briefs ) |
| C | ~50 | 10 wks. 2 x 3hrs / week ( all in workshop) Yr1 S1 (Drg output: mainly 2D drgs for laser cutter. Make: chassis, axles and 'bump' sensors. using laser cutting and fitting) | | Buggy (std parts supplied: circuit, electrical components, wheels) |
| D | ~ 150 | ~ 7 wks | At a local college machine shop | |
| E | ~160 | Yr 2, Oct-Feb (Represents ~25% of academic loading)<br>Drg output: engineering part drgs & GA | | Constrained brief (pump – repeated brief ) CNC for impeller & volute, m/c shop for bearing housing & shaft |
| F | ~250 | Yr1, 2 weeks full-time, design drgs given.<br>First prototype made from standard materials & tested (1 wk). Prototype redesigned and retested for improvements (1 wk). No m/c shop manufacture. | | Constrained brief. Water-powered rocket (mechanical students) and an aeroplane |

mechanical engineering courses only. Columns three and four give an outline of the time given to the Design and Make phases, respectively, and where possible, details of the types of drawing outputs.

## 3.1 Manufacturing time of the prototype

One of the key issues is the allocation of time and it can be observed that several universities run the Make over a week in full-time mode and immediately after the Design. Some universities avoid disruption to the delivery of taught units by timetabling this full-time activity during the examination period, whilst for university F the whole activity dominates the timetable for two weeks. It is interesting to note that the University of Bath, up until 2001, also ran the Make over one week full-time. However, the move to knit-in the manufacture of the prototype to afternoon slots, as shown in Table 1, meant that the timetabled teaching delivery was essentially unaffected. In order for the students to cope with the reduced time, a proof-of-principle prototype was made to demonstrate the functionality by interpreting their production drawings. To help students produce the parts, technicians would be on hand to explain why some of their production drawings would be difficult to manufacture and indeed assist the groups with some of the machining. The level of assistance could vary and whilst students would still have to assemble the parts it was deemed that important lessons in learning by their mistakes in manufacturing was being side-stepped in some cases. It was then decided to have all parts made equally by the group members using, when appropriate, traditional machine tools and engineering materials.

## 3.2 Design phase

The nature of the Design activity, in particular the Concept Design, will be governed by the type of brief set and as students develop their prototypes they will need to produce accurate order forms and complete engineering drawings for efficient working during the Make in Year 2.

### *3.2.1 Design brief*

The University of Bath's brief presents a *novelty design* where new tasks and problems are realised by original designs incorporating new solution principles. From Table 2, it can be seen that most other universities set a constrained brief where students use specified components or standard parts, but may need to undertake design of individual components. In contrast to the University of Bath, such briefs are repeated so that the standard parts can be reused. Also, repeating a constrained brief provides a spin-off that optimises the exercise's delivery and improves the staff's experiences in resolving student issues. At university F, students engage in a *Two Week Creation* [7] where the aerospace students are given a set of drawings for use as a pattern for the aeroplane, in week 1, which they will use to make and test the wings for lift. Similarly, at university E, students need to make an impeller, but have scope to design various configurations of vanes which are then tested for the head of water delivered. At university A, students use higher value standards parts, such as, microcontrollers, actuators and sensors to design a vending machine [6]. These types of briefs may be described as *adaptive design,* where the students keep to known and established solution principles and adapts the embodiment to changed requirements [5].

#### 3.2.2 Importance of students' engineering drawings

In order for students to manufacture their parts in the time slots scheduled, it is important for their solution to be designed for manufacture by the students themselves, not the technicians, and for the engineering drawings to adhere to the drawing standard [9]. At the University of Bath, the Design phase runs over five weeks and the groups are timetabled for two hours each week. When compared with the times at other universities in Table 2, it has fewer hours and therefore requires students to move steadily through the Design and Make process, shown in Figure 1, to give themselves time at the end to check the quality of each group member's engineering drawings.

#### 3.2.3 Ordering parts and materials

At university C, the continuous operation of the Design and Make phases are timetabled in a workshop which enables the technicians to deal directly with the ordering of materials at the point of enquiry without the need for a formal system. At the University of Bath, the Design phase is managed by academic staff in teaching rooms away from the workshop where the technician responsible for ordering the materials is based; so it is essential for students to appreciate the importance of fully specifying order details for their resources, which are purchased and prepared in their absence over the summer. Again, it is important for groups to keep to the manufacturing schedule and not waste time chasing alternative materials as a result of incomplete or inaccurate descriptions, quantities or cutting list dimensions on their order forms.

The technician responsible for ordering could attend the Design sessions, but it would be a demand on their time and not critical as the few errors incurred last year were easily resolved when the students returned.

### 3.3 Effect of group size

In order to manage large student numbers, the group size across institutions varies from five to eight. This year's cohort at the University of Bath is 240 and the group size must be calculated from the number of available workshop slots in the second year's timetable and the space for students in the Model Workshop at any one time. In previous years, students would make their prototypes at various small workshops throughout the Department of Mechanical Engineering, but in last year's activity, all groups manufactured and assembled their prototypes in the newly constructed Model Workshop. This was of some benefit to the students as they were able to use the same machines on which they trained in the first year's (EA1) workshop programme, but it introduced a logistical challenge in organizing all groups through the one facility. The group size at the University of Bath needs to be six and the Make phase is timetabled to stagger the groups through their allocated slots throughout the term, with a cushion of additional bookable slots for each group, if needed. At other institutions, the group size will be governed by all of the groups working simultaneously on a limited number of standard kits which may need higher group sizes.

## 4 MANUFACTURING RESOURCES

The Design and Make activity at the University of Bath further develops the students' workshop (EA1) skills by scheduling the student groups through the Model Workshop in the manufacturing phase. Engineering practice is a requirement of the UK-SPEC for accreditation and the Model Workshop is a commendable dedicated facility [8] for developing manual skills and understanding of machine shop capability, when they manufacture parts for their prototypes. However, this approach is not universal, see Table 1, as many universities issue *adaptive design* briefs which demand less of a workshop facility but more on selecting electromechanical systems and programming microcontrollers. At other universities the Make is confined to use of studio-type facilities and materials.  At university B, where students need to build the body of the buggy, a laser-cutter uses student dxf files to produce panels from MDF and Perspex, which then can be assembled with the help of tabs in the laser-cut profiles.

At the University of Bath, the bought-out parts from the three 'approved' suppliers are limited to £50 per group, but the materials from the University of Bath Resource List, have no charge. The ability for students to choose from a relatively wide range of resources means the solutions may be quite varied leading to some interesting principles of operation being demonstrated in the presentations, after which, they are disassembled for recycling.

## 5 CONCLUSION

The delivery of a Design and Make activity gives undergraduate Engineering students the opportunity to experience the design process from concept to the manufacture of a working prototype, but presents a challenge to universities in how they manage and finance resources, particularly for large student cohorts. The Design and Make process at the University of Bath is shown to follow Pugh's design core and illustrates how students can manufacture their own prototypes in a machine shop by using their practical skills developed in a workshop (EA1) programme.

With large student numbers it is also necessary to control the solution space by, for example, a timetable of workshop sessions which stagger blocks of groups through the Model Workshop during the first term of Year 2, which also avoids the need to 'farm-out' the Make to a local college or occupy a full week or more on the timetable. Additionally, it has been shown that for students to be efficient during the workshop sessions, they should produce, in the Design phase, engineering (CAD) drawings to a standard [9] and fully specify all materials and parts on order forms. Over the summer holiday, when the timetable is less busy, all parts can then be prepared for the students on their return.

A comparison with Design and Make activities on mechanical Engineering undergraduate courses at other universities shows two types of design brief exist. According to broad classifications [5], the University of Bath delivers a *novelty design*, where new solutions to the whole product are possible, yet at many other universities an *adaptive design* is delivered, where the solution is known but the embodiment is adapted to changed requirements.

In the adaptive design approach some universities develop additional skills by using standard hardware, software and components, which is considered important in industrial design education for alignment with emerging commercial trends [10]. This may take significant financial commitment and need to be repeated year-on-year to achieve payback. However, it does develop expertise from dealing with recurring problems and, arguably, greater efficiency in its delivery by academic and technical staff.

## ACKNOWLEDGEMENTS

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