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THE CHALLENGES FACING EDUCATION IN ENGINEERING DRAWING PRACTICE

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ABSTRACT

The Engineering Drawing has traditionally communicated the technical product specification (TPS) evolving to reflect technologies such as 2D and 3D-CAD as well as the full ISO Geometrical Product Specification (GPS). Although Model Based Definition (MBD) or Product Manufacturing Information (PMI) omit the use of drawing to communicate the TPS they lend themselves ideally to ISO-GPS methods. The methods present an opportunity to ensure Design and Engineering students are equipped with knowledge and understanding of GPS relevant to conventional TPS as well as PMI/MBD.

A survey of industry experts indicated expectation of good knowledge and understanding of the underlying GPS methods alongside traditional elements such as orthographic projections and line-types and a fair or good understanding of PMI/MBD application.

New materials and delivery structures were developed and implemented for the level 4 Design Media Unit; lectures were translated to seminars where the lecture element focused upon examples rather than rules with students applying the techniques using simple paper sketches. Throughout the series a simple scotch-yoke assembly was utilised, with rapid-prototyped physical working models and components distributed for students to work with; this provided familiarity of function, fit and form throughout the five week programme. The CAD tutorials utilised pre-modelled components identical to those used during the lectures. Students applied the methods practiced during the seminar and reinforced learning outcomes; students evaluated and recorded the appropriate fit, orientation and form tolerances to ensure system functionality with “worse-case” stack up. All components were considered together in order to maintain design intent and functionality.

Keywords: Engineering Drawing, GPS, Tolerancing, Education.

1 INTRODUCTION

The Engineering Drawing has been the mainstay of communicating the technical product specification (TPS) for more than four centuries and was first collated to a formal standard in 1927 as BS 308 comprising just 14 clauses. Since its inception it expanded to adopt relevant ISO standards as they developed, becoming three parts, and finally being replaced by BS 8888 in 2000 [1]. The most recent eighth edition, BS8888:2017 [2] now comprises 10 sections ranging from principles of specification, through to the application of full ISO Geometrical Product Specification (ISO-GPS) and in doing so draws on and connects 137 British and International standards.

A TPS definition can be distilled from Charpentier [3] and Nielsen [4] as the unambiguous functional specification of the work piece including permissible surface variance from the nominal model such that all components manufactured within the specification provide satisfactory functionality.

As Engineering Drawing practice has developed over time it has responded to new technologies such as 2D CAD and 3D CAD as well as evolving methodologies such as ISO-GPS. More recently, the 3D CAD environment has provided the backdrop for application of specification directly to the model rather than within a drawing using Model Based Definition (MBD) or Product Manufacturing Information (PMI). These methods lead to significant advantages in the transfer of requirement between organisations and operations such as translation from Model to Specification, Manufacture and Metrology. The emergence of ISO-GPS as the dominant method for specification lends itself ideal for conveying through PMI/MBD methodologies, however, the widespread use of these methods is currently limited by interoperability, user knowledge and standards compliance; more-over the benefits of PMI/MBD are dependent upon sound knowledge and understanding of ISO-GPS.

For Higher Education the new methods represent a challenge to ensure Design and Engineering students are equipped with knowledge and understanding of an increasing range of TPS techniques to meet the demands of both Academia and Industry; firstly, what should students be learning within TPS oriented units and how should this learning be delivered.

2 LEARNING STRATEGIES

For this work a combination of both primary and secondary research methods were used. A literature search and review of existing research established existing learning methods within the Academic sector while a review of core TPS text books for learning using the GPS method identified the foundation that typically supports TPS learning. Primary research was used to establish industrial expectation through a structured survey of industrial experts.

2.1 Review of TPS Learning

Although the ISO-GPS method is long established and extensively documented there is no definitive single point of reference available from the ISO. Within the UK BS8888:2017 does encompass the most significant elements and provides a comprehensive and integrated reference document for the designer. However, in common with most ISO and BS standards, it is a collection of rules and examples for guidance rather than a learning tool. The BSI does provide an educational guide for drawing practice [5] but is focused upon the "housekeeping" or presentational elements of line representation, dimension styles and drawing views rather than conveying functional design intent, where specification is introduced it provides examples to illustrate rules rather than methods to convey intent. The same issues are to be found within the established manual [6] dedicating the major proportion of material to housekeeping rather than specification of design intent. Where specification is covered the published work typically focuses upon the application of rules rather than establishing the specification through a logical progression from system functionality. This is also the case where innovative learning methods have been developed specifically to provide training in GPS methodologies through online learning tools [7-9] however, in these cases the audience is metrology where interpretation of specification holds importance rather than establishment from function. Although Nielsen presents a methodology for translation of function to specification [4, 10] this is only demonstrated in the handbook [4], confined to the appendices and represents just two components. Although the BSI has published learning objectives for training with the support of the Institution of Engineering Designers (IED) [11], there is *"..no specific guidance from either the Engineering Council or ..professional bodies on the requirements for accredited course content"*.

2.2 Industrial Expectation

To establish the link between academic learning and industrial expectation a panel of experts representing Automotive, Aerospace, Rail, Energy and Consumer Products was surveyed using a structured questionnaire against a table of specific learning outcomes related to the creation of TPS through the ISO GPS system and application in the PMI/MBD workspace. They were asked to indicate the level of expected knowledge of new graduate Design Engineers and Mechanical Engineers and indicate which outcomes should be the responsibility of the employer to meet or improve through training; they were also provided an additional comment section. Results indicate that graduates are expected to have good knowledge and understanding of the underlying GPS methods such as simple geometric tolerancing (GD&T), datums and theoretically exact dimensions (TEDs) alongside more traditional "housekeeping" elements such as paper sizes, Orthographic projection and linetypes; most also responded that Graduates should have a fair or good understanding of application through PMI/MBD. The panel found that additional employer training should be provided, predominantly in areas such as fits for hole-basis or shaft-basis, GD&T and application through PMI/MBD.

2.3 Existing Teaching method

Existing student learning of TPS has been provided within first year (level 4) Design Media CAD based unit. Here the subject has traditionally been taught through lectures where the drawing anatomy is described and the rules explained through examples (a similar structure to the established literature) prior to application using CAD toolsets in tutorials. Students were learning about the application of rules but not about the conveyance of design intent through the specification. Essentially, they were learning about component specification without knowledge or consideration of the system functionality. Moreover, they were creating individual component drawings in isolation from the interacting components and assembly. General weaknesses in the learning structure led to students to repeating the same mistakes found across the sector, such as too many views, over-dimensioning, poor application of tolerancing and a propensity to view the drawing as "lines" rather than a representation of the physical object. follow-on CAD units at level 5 were predominantly focused to modelling techniques while the expectation of quality TPS through indirect project units was limited.

2.3.1 Interim method

To alleviate some of the issues described a formative seminar and CAD tutorial were trialled. Students were provided a set of designer's guide notes featuring an annotated axonometric projection; here the component functionality was described in text together with the operational limits. For example, the specification of mating parts and required fit (normal running fit or press-fit) would be described together with component relationships from which students created a basic hand drawn TPS and applied annotation directly. The students then used the same note-set and methodology to apply annotation in CAD using a prepared component model and drawing template. For their "open-book" assessment, students were permitted any text books or notes and were provided a similar style of designer's notes & CAD model at the test. The quality of output from student assessment was appreciable higher than using the previous methods with most students able to derive the TPS from the functionality but struggled to discriminate between controlling functional surfaces and bulk material.

2.4 Strategy review findings

From review of learning strategies outlined above it was clear that a significant overhaul of learning method would be of benefit to both our students and the industry they will go to serve.
The key elements identified were:

- Existing teaching methods emphasize the "housekeeping" elements of TPS; this may be due to the prominence these aspects have held in traditional manual and 2D CAD drawing methods.
- Familiarity of component and assembly function is essential to provide a functional TPS.
- Learning material is predominantly rules based, describing specification in isolation.
- Industrial expectation of student knowledge is low.
- The TPS describes the limits of functionality.
- Understanding the expression of specification is more important than understanding the tools.
- A clear three step procedure should be presented to follow:

1. Functionality (form and size control of functional surfaces)
2. Kinematic relationship (orientation and location relationships between functional surfaces)
3. Bulk material (control of non-functional surfaces).

3 NEW LEARNING STRATEGY

To implement the findings above, a programme was developed to promote the learning of GPS based TPS through system functionality. Essential to the strategy is familiarity with components and assembly where the whole can be analysed from a functional perspective and each to their individual and collective kinematics; in this case a Scotch-Yoke mechanism was chosen to provide the functional model throughout the programme.

3.1 Prepared material

To support the programme each week's activities were supplemented with comprehensive note packs, presentations, models and artefacts. In the case of CAD tutorials, the main set of notes supporting weeks 3-5 detailed each stage of application; moreover, the decision process and justification of tolerance specification. Students were also supplied with a full set of CAD models representing the components of the Scotch-Yoke assembly and customised, standards compliant, templates.

The formative seminars were supported through the presentations, student notes, the SEED guide for limits and fits [12] as well as physical artefacts of Scotch-Yoke assemblies and components (Figure 1). Each assembly comprised: 2x shaft elements manufactured from Ø6h8 BS1407 Silver steel; 2x Ø6 ID Igus top-hat bushings; 2x Ø6 ID Igus plain bushings; 1x Yoke; 1x Eccentric; 1x Body. The yoke, eccentric and body were produced using Makerbot 3D printing machines from the same part files students used in the CAD labs.

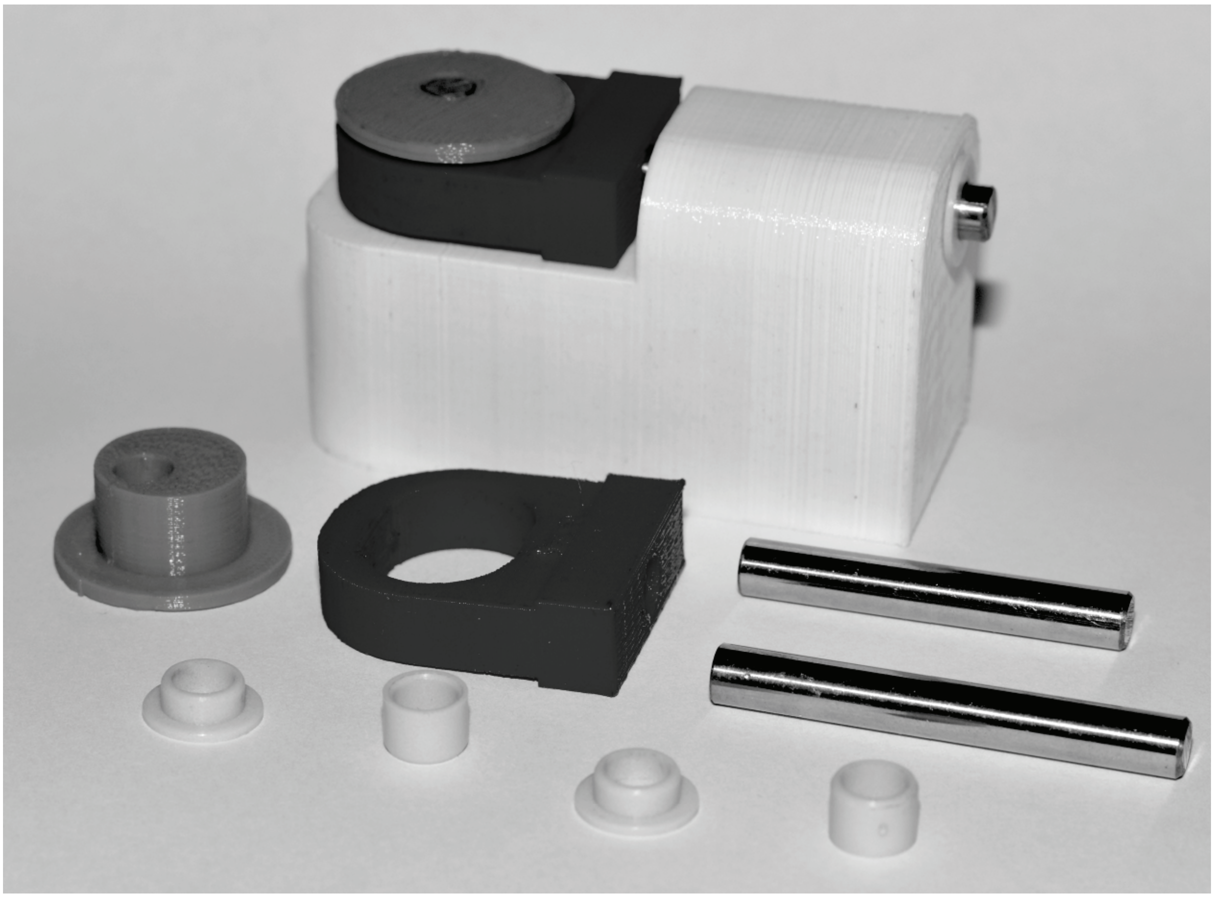

Figure 1. Scotch-Yoke parts and assembly

3.2 Implementation

The programme was delivered over five weeks with a 2hr split lecture with formative seminar followed by a 2hr CAD based tutorial using Solidworks. In each of the lecture-seminars the first hour was used to formally present the core concept of a topic. The second hour provided the formative seminar with students able to immediately apply the concepts through the traditional medium of pen and paper; the formative nature ensured they gained direct feedback as they applied the described techniques. The repetition of application from this natural interface to the unfamiliarity of CAD annotation tools took place in subsequent CAD tutorials where the work was more formally presented and calculated with descriptive work-sheets. To provide familiarity of function the Scotch-Yoke mechanism was used throughout the lectures, provided as physical components and working assemblies at all seminars and as CAD models for the CAD tutorial TPS implementation stage.

3.2.1 Primer

Prior to commencing the main programme, students were introduced to customised, standards compliant, templates and provided CAD models of the Scotch-Yoke components. Students assembled the part models using appropriate assembly mates that reflected the functionality and informed system functionality.

3.2.2 Week 1:

The first lecture introduced the drawing anatomy and housekeeping elements such as linetypes, lineweights, paper-sizes and orthographic projections.

For the formative element students sketched each of the parts of the Scotch-Yoke assembly in 3rd Angle projection. The emphasis was on correct angle of projection and minimum number of views and students asked to sketch for quantity of practice rather than quality or reproduction.

For the CAD tutorial students laid up an unannotated 3rd angle projection drawing for each of the components and created a fully annotated assembly drawing.

3.2.3 Week 2

The second lecture analysed mechanisms and assemblies identifying key descriptive parameters for identifying and discriminating between functional surfaces, kinematic parameters and performance parameters. The functional surfaces interact with other components and were described in the context of geometric tolerance form descriptors such as flatness and cylindricity before examining features of size, classification of fit and the envelope requirement.

For the formative seminar students examined the Scotch-Yoke assembly and, with the aid of annotated axonometric sketches, identified functional surfaces. They further identified features of size and classification of fit: clearance or interference (students did not consider transition fits).

For the CAD tutorial students used the assembly drawing to identify and note each of the fits between features of size. Each hole-shaft fit was annotated as a pair of drawings and the resultant fit combination recorded along with value of clearance or interference calculated.

3.2.4 Week 3

The third lecture examined the kinematic parameters briefly described previously. These parameters expressed the relationship between functional surfaces within the component and used geometric tolerance orientation and location descriptors such as profile of surface, position, perpendicularity, and co-axiality relative to a Datum system.

For the formative seminar students examined the assembly and identified the relationships between functional surfaces. They derived a datum system from the functional surfaces to constrain each subsequent functional surface using the described orientation and location tolerances. Students were not expected to use the correct symbols but to understand the concept.

The CAD tutorial utilised the calculated fits to inform the tolerance zones identified during the formative seminars. Students applied a datum system based upon the functional surfaces to control the limits of orientation position between all functional surfaces within the components while allowing the assembly to function. Students worked through the part drawings, recording and collating tolerance zones to finally calculate the available clearance between surfaces at the yoke to perform a “worse-case” tolerance stack and ensure functionality at extremes of form and fit.

3.2.5 Week 4

The fourth lecture examined the remaining surfaces, the method of control and introduced theoretically exact dimensions (TEDs). The remaining surfaces represented the bulk material that holds the functional surfaces in position; essentially, they can be described as performance parameters. The surfaces were controlled with looser tolerances than the functional surfaces and utilise indicators such as “all-over” and “all-around” to simplify application.

For the formative seminar, students again drew up axonometric sketches of the components and marked up functional surfaces prior to controlling the remaining surfaces using the described methods. Finally, students applied TEDs and marked off each surface as constrained.

For the CAD tutorial students identified the uncontrolled non-functional surfaces, applying relevant tolerances to individual or collected surfaces. Only after completion of all surface tolerancing were the TEDs applied; this often required the adjustment of tolerance placement within the drawing space.

3.2.6 Week 5

For the final week only the lecture element was delivered. This was a summary of the four preceding weeks and was divided into five colour coded sections to aid revision:

- Housekeeping; Purpose, paper sizes, line types and weights, 1st and 3rd angle projections.
- Functional parameters; Functional surfaces, features of size, fits.
- Kinematic parameters; Geometric tolerances, orientation & location of functional surfaces.
- Performance parameters; Geometric tolerances, location and form of remaining surfaces.
- Method of application; Function, kinematics, performance.

3.3 Issues identified

During programme delivery it was clear that students expected to use the SEED guide for limits and fits [12] for all of the fits within the assembly, however, the actual component fits of the bought out parts precluded this; bush/shaft clearance fits were E10/h8, body/bush interference were H7/s7, eccentric/shaft interference fits were S8/h8. To address this either the fit will be changed to suit the guide or, preferably, a revised guide based upon the existing documentation.

The programme was delivered to four groups of product design students, one of industrial design and two of design engineers. Some of these were scheduled for CAD tutorials before their Lecture/seminar delivery and therefore the follow on CAD tutorials were delivered the following week. This, of course, meant some students had received two lecture/seminars before their first CAD tutorial and resulted in some failure in translating learning from the formative seminar to the tutorial practical.

4 CONCLUSIONS

The programme met the requirements of the learning strategy and findings of the review. Students gained knowledge and understanding of GPS methodology through the practical application to a single assembly of components. Students developed a first-hand familiarity and understanding of system functionality essential to apply an effective GPS scheme to the component parts. By using the formative seminars students could visualise the components in three dimensions and avoid the problems with regarding drawings as collections of lines rather than the components they represent. Students were prevented from developing bad-habits, such as applying linear tolerances to non-features of size, by leaving the application of dimensions to non-features of size until last. This last point is particularly relevant for students progressing towards the use of PMI/MBD methods where there might not be any TEDs at all, since the model is the TEDs.

The programme makes a significant step towards meeting the objectives of the BSI & IED [11] and exceeds Industry's expectation of graduate knowledge in the fundamental techniques.

Finally, student learning has not yet been formally assessed. However, we are confident that the new programme represents a significant step-up from the established methods used previously and elsewhere.

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