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Tool design for a competitive world

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ABSTRACT: Tool design is one of the key, traditional courses in the manufacturing engineering curriculum. Revolutionary changes in computer hardware and software technology on the one hand, and the profound impact of the global market-based economy on the other, have changed tool design concepts, needs and methods significantly. Also, engineering education research reveals that student comprehension is significantly improved by involving them in real world-based, *hands-on* projects in a collaborative learning environment. Consequently, pedagogy in tool design should be modified based on real world needs, using the latest available technologies. In this article, the authors outline their approach to teaching tool design. Computer-based instruction, research/industry supplied projects, parametric solids and assembly modelling-based design, rapid prototyping-based verification, team-based activities and project-based homework are the major features of the approach.

INTRODUCTION

In recent years, owing to the World Trade Organization (WTO) agreements and business globalisation, a new era of global trade has emerged. Industries today have to compete not only with local and regional rivals, but also with competitors from all over the world. Global competition has created major challenges and opportunities for industries. On the one hand, many previously unknown and nonexistent companies now offer goods and services at a competitive level of quality and price, on the other, a big market of global proportions is now available to companies. The keys for success in this competitive environment are high product quality, low cost, and rapid response to customer's needs. Tools have always been a major element in any manufacturing industry. The challenges and opportunities created by the new global market have significantly changed the way people look at tools. Flexibility, modularity, low cost, and quick design and fabrication are now considered as the basic requirements for any tool.

Revolutionary changes in computer hardware and software technology have facilitated the tool design, verification and fabrication processes, and have rendered them more effective from standpoints of time and cost. Because of the two above-mentioned reasons (global economy and technology advancements) a revision of the tool design process is an imperative. Consequently, tool design pedagogy and tools should be modified based on real world needs, using the latest available technologies.

BACKGROUND AND APPROACH

Tool design is defined as analysis, planning, design, construction, and the application of tools, methods and procedures necessary in order to increase manufacturing productivity [1]. It has been one of the key, traditional courses in manufacturing engineering programmes. Single and multi-point cutting tools design, work holding principles, jig design, fixture design, gauge design, tool material selection, tooling for polymer processing, sheet metal fabrication tools design, dimensioning, tolerancing, and rapid prototyping are the main topics in this course.

In fall 2000, a new undergraduate degree in Manufacturing Engineering was initiated at Texas State University - San Marcos in San Marcos, USA. Curriculum development efforts for this programme were driven considerably by a study conducted by the Society of Manufacturing Engineers (SME) entitled *Manufacturing Engineering for the 21st Century* [2]. Another driver was the criteria laid down by the Accreditation Board for Engineering and Technology (ABET). The SME study identified communication skills, teamwork, project management, business skills and life-long learning as some key competence gaps in recently graduated engineers. A senior capstone design course was designed specifically to address these key skill deficiencies. Also, many other courses were redesigned to meet SME and ABET concerns. Specifically, the restructuring of the tool design course focused on the utilisation of state of the art technologies, teamworking, hands-on activities, and for student understanding of the entire design-to-fabrication process.

The University's approach was significantly impacted by the student demographics there. Currently, the percentages of Hispanic and female students are at 19% and 57%, respectively. Several studies in science and engineering (S&E) education suggest that women and minorities are relational learners and prefer to engage in collaborative learning [3]. Significant numbers of these students drop out of S&E programmes because traditional engineering education is oriented towards abstractions and the algorithmic approach, as well as encouraged individual accomplishments. Thus, the traditional approach ignores the learning styles of women and minorities.

Therefore, the University's pedagogical approach is both relational and involves the team approach to project completion. The relational approach basically includes homework/projects at the end of each major topic, such as single point cutting tool design, gauge design, fixture design, etc. However, the traditional approach to instruction in tool design features projects that are unconnected; ie the assignment in single point tool design does not interface with the assignment in fixture design.

Thus, these activities come across as exercises in isolation. As a remedial measure, the approach utilises a unified product (to be detailed later) through the entire semester for which various tools such as jigs, fixtures and single point cutting tools are designed at appropriate points in the semester. Each such tool design activity, which is undertaken independently by every student, is considered as homework. Additionally, a term project is issued as well for which the required tooling is designed and fabricated by a team of students.

METHODOLOGY

The highlights of the tool design course can be summarised in the item detailed below.

Use of State of the Art Technologies

To prepare students for professional practice, the latest commercial software are being applied in this course. *Pro/Engineer* is the official CAD software for all of the geometric modelling activities in this course. In addition, other related software are used in related course topics, such as:

- *E-Factory*;
- Online engineering calculator [4];
- Carboloy online cutting tool selection catalogue [5].

From a fabrication and prototyping standpoint, two rapid prototyping machines (Helisys LOM 1015 and Stratasys FDM 3000), plus two Haas CNC machine tools, are used.

Hands-On Projects

A term project accounts for 30% of the overall grade, and included CAD, fabrication, reports and presentations. At the beginning of the semester, students form teams of 3 or 4 members. Projects generally consist of design, fabrication and final assembly of a tool for a specific product. The final prototype might be a functional tool or a mock-up for visualisation purposes. Great emphasis is placed on the requirement that project topics be research/industrial supplied. Several topics are offered by the course instructor from their current research projects. In some circumstances, students have selected their projects based on a tool need that stemmed from their workplace.

Each team is comprised of students who are experts in design (computer aided design) or fabrication (machining, welding, etc). The design activities are undertaken in *Pro/Engineer*. Upon completion of the preliminary design, students create prototypes of the design on either the LOM 1015 or FDM 3000 rapid prototyping machines. In some cases, additional processes, such as machining and/or assembly, are also required. Based on an analysis of the physical prototype, design modifications are undertaken.

Unified Product-Based Homework

Each week, homework is assigned to students as an individual assignment. Homework are generally submitted electronically and account for 20% of the grade. All homework are related and follow the same goal: design of various tools for a unified product. For example, most recently, the unified product that students worked with was a temperature measurement stand (see Figure 1), which is for the manufacture of the many parts and components of the stand that various design projects were issued. The temperature measurement stand design activity was issued at the beginning of the semester. Students undertake specific part/component's tool design at the appropriate point in the semester, when a major topic has been covered, such as fixture design.

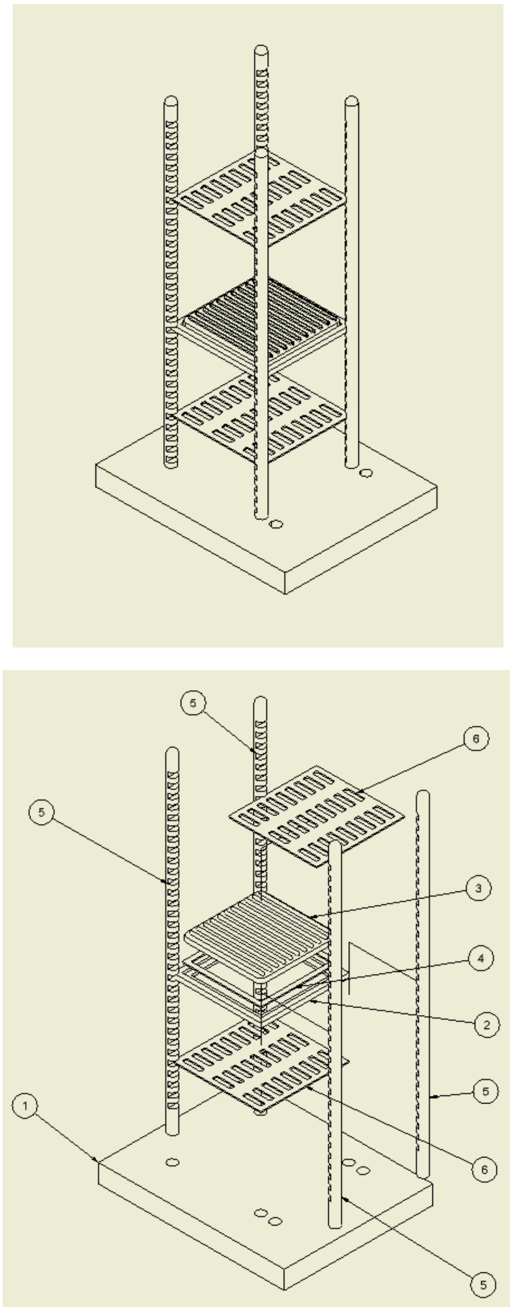

Figure 1: Example for the reference design: Temperature measurement stand: 1. Base, 2. Support, 3. Heater element, 5. Insulator, 5. Shaft, and 6. Vent

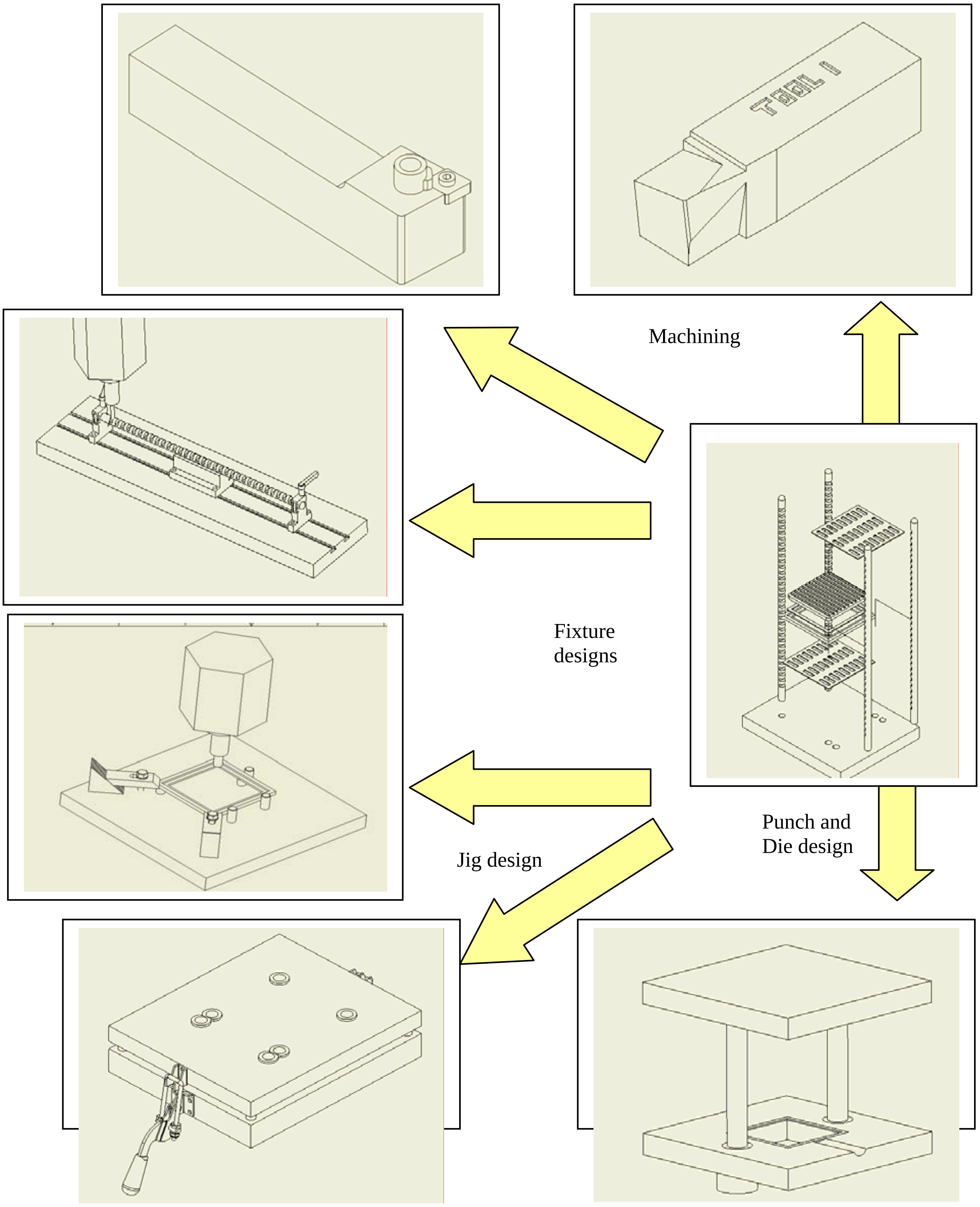

Figure 2: Homework assignment based on reference design.

In summary, the steps listed below explain the course timeline.

- *Week 1*: At the beginning of the semester, the instructor explains a need for a simple design for a research experiment. Detailed explanations are provided on the problem, the roadmap to solve the problem, and the tools needed for the solution. Therefore, students understand the product design, which in turn has a crucial impact on the subsequent tool designs. This unified product design will be the first homework for students.
  Example: In a new rapid prototyping process development, uniform heat generation is a necessity. Among several identified flat heaters, the one with the most uniform heat generation will be selected. Design of a simple stand is needed that will facilitate precise temperature measurement in a periodic increment in the XY plane.
- *Week 2*: The instructor evaluates all designs and picks the best one as the reference design for the rest of the semester. He/she may effect minor modifications to the design to render it applicable for the ensuing step (step 3). Example: Figure 1.
- *Weeks 3-14*: Each week, depending on the lecture topic, one part of the reference design is selected and the appropriate tool is deigned for the same. A week past the homework submission, the instructor gives

feedback to students and the best design(s) is (are) distributed.

Example: The stand includes several parts. In the week where the lecture topic is the single point cutting tool design, relevant homework in designing a proper cutting tool for the four shafts in the reference design is issued. In the week that the instructor talks about jigs, the homework requires the design of an appropriate jig for making six holes in the base, etc. Figure 2 illustrates how the design of specific parts/components of the temperature stand map into activities, such as a single point cutting tool design (hss and carbide insert), fixture design, jig design and punch and die design. Specifically, with reference to Figure 1, the single point cutting tool design involves the machining of the shafts (part 5), the fixture design involves milling slots into the shafts and milling the support (part 2), the jig design involves drilling holes in the base (part 1) and finally the punch and die design involves the blanking operation for the insulator (part 4).

Utilising this unified product-based homework method, students see the whole picture and become more familiar with the overall purpose and aspects of tool design while they learn individual topics.

Writing and Communication Skills

The tool design course places great emphasis on writing and communication skills. Multiple reports and presentations are required during the semester Also, as bonus work, students are asked to prepare their reports in a conference paper format. They are encouraged to submit their work to a related conference/symposium, preferably before the end of semester. Among the five projects completed in the spring 2005 semester, three papers have been accepted and presented in two peer-reviewed conferences, namely:

- *Industrial Engineering Research Conference* (IERC 2005) [6];
- *Solid Freeform Fabrication (SFF) Symposium* [7][8].

RESULTS

The reengineering of a tool design course was necessitated by pressures of global competition and advances in computer technology. The authors consider the impacts of the new global market and advances in computer technology, and the changes that have been implemented in a tool design course, specifically computer-based teaching, research/industrial-based project, and project-based homework, which are the some of the major innovations that were affected.

The experience gained so far is that students reacted very favourably to the project approach. Working on a research project also seemed to motivate students to consider pursuing graduate studies in manufacturing.

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