World Transactions on Engineering and Technology Education
Vol.6, No.2, 2007

Developing the research aptitude in senior year manufacturing engineering students

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ABSTRACT: This article chronicles experiences with individual research-paper projects in teaching a senior level course on *Polymer Properties and Processing* to manufacturing engineering majors. The course exposes students to current trends in the plastics and composites industry as a means of preparing them for graduate study. Accordingly, in this course, rather than assigning team-based projects, research paper topics were assigned on an individual basis. Independent research activity develops the research aptitude early in the career, prepares students for graduate studies, develops independent thinking, and makes students responsible for their learning. Students were systematically prepared for taking up this research paper activity by means of a proper selection of topics, research laboratory demonstrations and plant tours. Students prepared a 10-12-page research paper and delivered a 10-minute presentation. The output of this activity has been very encouraging. Out of 10 students, three have accepted jobs at Toyota, Chrysler and Boeing, and are committed to graduate studies. One student is working as a research assistant and has co-authored two conference papers in the bio-based composites area. In this article, the authors detail the pedagogy and the research paper activity.

INTRODUCTION

Manufacturing Engineering is a relatively new and small programme that started in 2000 at the School of Engineering at Texas State University, San Marcos, USA (see Table 1). The *hands-on* curriculum includes laboratory experiences in Computer-Aided Design (CAD), Rapid Prototyping (RP), robotics, microelectronics manufacturing and computer integrated manufacturing. The Manufacturing Engineering programme is scheduled to undergo ABET accreditation in autumn 2008. Companies such as Toyota, Chrysler, Northrop Grumman, Boeing, National Instruments, etc, have hired graduates from this programme.

Table 1: The enrolments and number of graduates in the BS in Manufacturing Engineering at Texas State University.

	2006	2005	2004
Enrolments	93	75	79
No. of Graduates	18	17	14

Although the curriculum emphasises *hands-on* and team-based learning, it does little formally by way of preparing students for graduate studies. The School is in the process of collecting data pertaining to the number of students enrolled for graduate studies, but this number is very small. Secondly, the major thrust in the present manufacturing curriculum is towards metallic materials and processes. Majors in manufacturing engineering have very limited knowledge of plastics and composites. This fact was revealed while teaching other courses like Computer-Aided Engineering [1].

The course of *Polymer Properties and Processing* was offered for the first time in spring 2006. In this course, rather than assigning team-based projects, research paper topics were assigned on an individual basis. The intent of the research paper was that it would serve as a major learning tool. The students were systematically prepared for taking up this activity. Demonstrations were organised in the chemistry laboratory on polymer characterisation techniques, including Gel Permeation Chromatography (GPC), Thermal Gravimetric Analysis (TGA) and Dynamic Mechanical Analysis (DMA). Plant tours were organised to expose students to different plastics and composite manufacturing processes.

Manufacturing Engineering majors are required to take two electives from the manufacturing processes group, which contains five courses. The *Polymer Properties and Processing* course is one of those five options. Ten students enrolled for the course. Considering the total enrolment in the Manufacturing Engineering programme and the fact that the course was offered for the first time, 10 students constituted a good enrolment. Students had the prerequisite knowledge gained from the *Materials Engineering* and *Materials Selection and Processes* courses. Topics in the course were selected so that they would help students in their research papers. The topics in the course were selected from two different texts and are as follows:

- Polymer Materials – Molecular Structures, Microstructures and Polymerisation;
- Characterisation, Applications and Manufacturing of:
  - Thermoplastics;
  - Thermosets;
  - Polymer Matrix Composites (PMC).
- Environmental Aspects of Plastics and Composites;
- Introduction to Bio-Based Composites and Nanocomposites [2][3].

TEACHING STRATEGY

This course was taught twice a week for one hour and 15 minutes. It was a combination of lectures, videos, plant tours

and research laboratory visits. Three plant tours and one research laboratory visit was organised. Ten videos were shown and discussed in the class.

The following polymer characterisation techniques were demonstrated in the Polymer Chemistry laboratory; these techniques were briefly explained in the class prior to the visit:

- Dynamic Mechanical Analysis (DMA) for the viscoelastic behaviour of polymers;
- Gel Permeation Chromatography (GPC) for the evaluation of molecular weight;
- Thermal Gravimetric Analysis (TGA) for evaluating mass loss.

The three plant tours were organised in the local industry in San Marcos, specifically:

- Stellar Plastics: injection moulds and injection moulding [4];
- Flex-Tech Hose & Tubing: extrusion [5];
- CFAN: manufacturing of *carbon/epoxy composite fan blades* for jet engines [6].

For better understanding, videos on manufacturing processes were showed in the class. These videos have been prepared by the Society of Manufacturing Engineers. Detailed notes were provided before showing a particular video. Students were asked to read through these notes before watching the videos. By this method, students would watch each video carefully and not divert their attention by writing notes. Table 2 explains the schedule on a weekly basis pertaining to teaching, plant tours, laboratory visits and research paper activities.

PLANT TOURS

Plant tours were regarded as a major learning source for the research paper activity. Students had the opportunity to talk to researchers, engineers and management personnel in order to understand the importance of a research aptitude in their career. All the plants visited engaged themselves in solving challenging problems and were not merely production shops.

Research Laboratory Visit: Institute of Environmental and Industrial Science (IEIS)

The Institute of Environmental and Industrial Science (IEIS) at Texas State University has a state-of-the-art laboratory for polymer characterisation consisting of DMA, TGA and GPC [7]. Students were demonstrated DMA, TGA and GPC techniques. Also, some of the current research activities in the IEIS, such as bullet-proof, self-healing polymers; polymer nanocomposites; and bio-based resins, were discussed. Students were inspired by watching graduate students and researchers in action.

Plant Tour 1: Stellar Plastics

Stellar Plastics develops specialty injection moulds for reputed firms such as Dell and Toyota [4]. The President and Vice-President of the company accompanied students during their tour. They provided insights on designing with plastics components. Many challenging injection moulds were exhibited. Stellar Plastics also engages in the regular production of injection-moulded parts. Students were able to watch the entire cycle of part production on injection-moulding machines.

Table 2: The schedule of activities on a weekly basis.

Lecture Topics	Video	Plant Tour	Research Paper
Stage I: Polymer Properties and Characterisation (weeks 1-3)			
1. Polymer materials: molecular structures, microstructures and polymerisation 2. Mechanical, chemical and physical properties 3. Basics of polymer characterisation: DMA, GPC and TGA	1. Introduction to plastics	1. Research laboratory: demonstrations of DMA, GPC and TGA	1. Introduction to research paper activity: 3rd week
Stage II: Thermoplastics, Thermosets and Polymeric Composites: Materials and Applications (weeks 4-8)			
4. Commodity thermoplastics 5. Engineering thermoplastics 6. Thermosets 7. Composite materials, basics 8. Constituent materials: properties and applications	2. Polymer production techniques 3. Composite materials 4. Plastics injection moulding 5. Plastics extrusion	2. Stellar Plastics 3. Flex-Tech Hose and Tubing Company	1. Details about research paper activity: 7th week 2. Topic finalisation: 8th week
Stage III: Thermoplastics, Thermosets and Polymeric Composites: Processing (weeks 9-12)			
9. Injection moulding 10. Extrusion 11. Blow moulding 12. Plastics machining and assembly 13. Manual and spray lay-up 14. Vacuum Assisted Resin Transfer Moulding (VARTM)	6. Plastics injection moulds 7. Plastics blow moulding 8. Plastics machining and assembly 9. Manual lay-up and spray lay-up 10 Filament winding	4. CFAN Company	3. Discussions on research paper resources and samples reports: 9th week 4. 1st progress report: 11th week
Stage IV: Research Paper Examination (weeks 13-14)			
15. Final report and presentation discussions 16. Research paper final examination	----------	----------	5. 2nd progress report: 13th week 6. Final report and presentation due: 14th week

Plant Tour 2: Flex-Tech Hose and Tubing

Flex-Tech produces rigid and flexible tubes and pipes using the extrusion process [5]. Students had the opportunity to understand the entire extrusion system. They also had the chance to see the assembly of the extrusion screw and how the extrusion system is started at the beginning of production. There was also the problem of *melt fracture*, and engineers at Flex-Tech explained the reasons and troubleshooting methodology. It was a three-hour-long visit and students learned a lot that could not be explained in regular lectures.

Plant Tour 3: CFAN Company

CFAN was created by GE Aircraft Engines and SNECMA, two leading aerospace companies that manufacture very high precision parts using advanced performance composites such as jet engine fan blades [6]. Students had the opportunity to watch prepreg cutting, manipulating cut pieces of prepreg on 3D complex moulds, vacuum bagging and autoclave, and post-curing. At the end, engineers at CFAN showed a short video explaining the challenges that CFAN has to meet in producing high-precision components. This was a most exciting plant tour and students were really charged with the area of composites manufacturing.

RESEARCH PAPER ACTIVITIES

Research Paper: Introduction (3rd and 7th Week)

A brief explanation was made about the purpose of research papers; the nature of the work; and other expectations in the 3rd week. A weight of 30% was given to the research paper. At the end of 7th week, details of the research paper activity were provided. By this time, students had amassed a good understanding of basic polymer chemistry, polymer characterisation, thermoplastics, thermosets and polymeric composites' properties and applications, as well as different manufacturing techniques. The document explaining the purpose of the research paper, formats of progress reports, the final report, *PowerPoint* presentation and important due dates was circulated. Also, few sample research papers were distributed so that students had clear idea about this activity.

It was expected that students would select a topic that had current importance (such as polymer nanocomposites). Later they would collect information from different sources such as research articles, handbooks, magazines and Web sources. They were also encouraged to visit the industry and research laboratories. They were expected to compile a 10-12 page research paper and deliver a 10-minute presentation in front of the entire class. It was expected that students would have at least 15 technical references from mixed sources. It was insisted that each paper must comprise the section: Abstract, Introduction, Conclusions, Future Scope and References. Students were asked to bring their own topics in the following week. The instructor suggested few topics, such as polymer nanocomposites, bio-based composites, and polymers in Noise, Vibration and Harshness (NVH) applications.

Research Paper: Topic Finalisation (8th Week)

Research paper topics were finalised in the 8th week. The majority of the topics were related to polymeric composites. The instructor helped students to narrow broad-based topics into focused topics (such as polymer nanocomposites for high-temperature applications). Students brought all their collected material when meeting with the instructor. Some of the final topics were as follows:

- Polymer nanocomposites for high-temperature applications;
- Carbon fibre reinforced composites in aircraft applications (case studies on fuselage, wings and fan blades);
- Recent trends in polymers and composites in automotive applications;
- Polymers in NVH applications;
- Recycling of thermoplastics waste;
- Fibre-Reinforced Polymer (FRP)-reinforced concrete;
- Characterisation and applications of bio-based composites.

Two progress reports were expected: one after two weeks and other after four weeks from the date of the finalisation of the specific research paper topic.

Research Paper: Resources

In the 9th week, various resources for gathering information regarding research paper were discussed. The instructor had set up time with each student to discuss probable sources for the literature review. The instructor shared handbooks (eg refs [8-10]), books, magazines, research papers and personal contacts within and outside the University.

The instructor assisted students by helping them visit the Web sites of the National Composite Center (NCC) and Lightweight Structures BV [11][12]. These research organisations engage themselves in applied research. The NCC has developed composites leaf springs, pickup truck beds, FRP bridge decks, and FRP temporary runways. Lightweight Structures BV has developed a composite safety barrier, lighting columns, crash cones for trucks and truck trailers. Students were excited to see the enormous applications of composites in the real world.

The instructor demonstrated to students how to search for related research articles and how to get a full script using database sources available through the University's library Web site. The instructor's graduate research assistant also helped students in obtaining the required articles.

Research Paper: First Progress Report (11th Week)

It is very important to monitor the progress from time to time to avoid any surprises. Students were asked to come up with the outline of the paper as a first progress report. The outline would help students to narrow down the vast information they had collected. The outline of the paper was finalised for each student. The instructor discussed everybody's progress report and presentation in front of the entire class. The feedback to individual students helped others as well. They were urged to mention each and every reference, which is part of professional ethics. They were advised to use ample visual information (eg pictures, figures, tables and charts).

Research Paper: Second Progress Report (13th Week)

As a second progress report, students were asked to bring a one-page abstract, one-page introduction, conclusions in bulleted form and references. It was observed that students were more inclined to write in detail about manufacturing processes but were applying less effort in the fundamental understanding and elaboration on specific applications. This was an obvious

outcome as manufacturing engineering students do not have a strong background in areas like fluid mechanics, mechanical vibrations, dynamics and the strength of materials. Some students were advised to present their information in the form of two or three case studies. Students were also asked to bring the title, introduction and conclusion slides in *PowerPoint*.

Research Paper: Final Report and Presentation (14th Week)

Students were asked to bring their final reports and final *PowerPoint* presentation. It was expected that each report would have 10-12 pages excluding the title page. Each *PowerPoint* presentation would have about 15 slides excluding the title slide. The instructor mainly provided feedback on the *PowerPoint* presentation. The feedback was focused on missing information, improper technical flow of the slides and formatting. The lecture room with a projector was made available to students for mock presentations.

Research Paper: Examination (14th Week)

Two external evaluators with broad industrial/research experience were invited to assess the performance. One of the motives of the research paper was to generate interest among undergraduate students in performing research. Therefore, it made much more sense to invite active researchers as evaluators. Their feedback would help in improving this activity. The external evaluators considered how each manufacturing engineer student comprehended the science and application of polymeric materials. The hardcopy of the final report and a softcopy of the *PowerPoint* presentation were given to these evaluators one week before the examination. Each student was expected to deliver a 10-minute presentation that was followed by a two-to-three minute question/answer session. Students were graded by the instructor and external evaluators on the basis as displayed in Table 3. The average score for written reports was 85%, whereas the average score for presentations was 66%.

Table 3: The basis for research paper evaluation.

Report
1. Creativity
2. Completeness and depth
3. Knowledge of engineering science
4. Use of appropriate engineering terminology
5. Conclusions
Each item 20 points; total out of 100
Presentation
(a) Presentation Skills
1. Speech volume, projection and pronunciation
2. Quality/clarity/quantity of visual aids
3. Use of time
(b) Questions and Answers
4. Directness and clarity of answers
5. Display of knowledge/competence
Each item 10 points; total out of 50

CONCLUSIONS

Out of 10 students, three have accepted jobs at Toyota, Chrysler and Boeing, respectively, and are committed to graduate studies. One student is working as a research assistant and has co-authored two conference papers in bio-based composites. Although these numbers do not assume statistical significance, they definitely indicate encouraging results.

External evaluators were active researchers with wide industry experience. They felt that the research paper activity would prepare undergraduate students for interdisciplinary research. They seemed to be interested in recruiting students on their active research project. This fact attests to the quality and success of the research paper activity.

Students took the initiative in revisiting the polymer research laboratory, visiting local composite manufacturing plants, visiting the library at the University of Texas at Austin, and requesting sample materials from companies. Many of them used Sci-Finder and other databases. Almost everybody used four-to-five journal article references in their report. These activities indicate that they developed a research aptitude and independent thinking.

It was also observed that students who took this course considered polymeric materials when selecting materials for their capstone project. Four students requested that this course be offered as a special topic in spring 2007. One other undergraduate student, who received the Houston-Louis Stokes Alliance for Minority Participation Scholars Program (H-SLAMP) scholarship, is working with the first author on bio-based composites research and will be participating in a student poster competition. All of these results indicate that this course has generated awareness and interest about polymeric materials.

This course will next be offered in spring 2009. Hands-on components will be added in the next cycle of teaching. The research paper activity will be continued to evaluate this particular teaching approach.

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