FUTURE DIRECTIONS FOR PLASTICS ENGINEERING EDUCATION: TECHNICAL, BUSINESS, AND HUMAN CONCERNS

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Abstract

Engineering practice in the plastics industry typically requires knowledge of materials science, mechanical design, and manufacturing processes. However, the traditional academic focus on these technical fundamentals may not be sufficient to satisfy recent trends in industry practice. This paper reflects on the current state of plastics engineering education and proactively suggests changes in the curriculum to address the needs of the global system of the plastics industry through the three domains of technical, business, and human concerns.

Introduction

Plastics engineering is a necessary and desirable discipline. The year 2000 U.S. economic data indicates that plastics engineering is of vital importance, employing 2.4 million people that collectively contribute $421 billion to the gross national product [1]. However, there are varying reports on the state of plastics engineering education and careers. For instance, a recent article [2] indicates a significant shortage of engineers in the German plastics industry, and advocates a need to make technology and engineering education "fun" so as to attract and retain more students in the discipline. This report is contrary to the current state of the industry in the United States. After more than ten years of 100% placement, plastics engineering students graduating from our department in the last year have had difficulty finding gainful employment.

Recent socioeconomic trends bear directly on the plastics industry and future directions for plastics engineering education. Specifically, there has been an escalation in the outsourcing of polymer production, product design, mold making, and parts production to lower cost, offshore suppliers [3]. This escalation, coupled with a downturn in the U.S. economy, has dramatically reduced U.S. business investment in plastics processing equipment and machinery to a standstill [4]. Together, these trends dictate a changing role for plastics engineers and require a retraining in the plastics engineering workforce for engineers to remain competitive.

This paper reflects on the current state of plastics engineering education and proactively suggests changes in the academic curriculum and professional training to address the changing global system of the plastics industry through examination of the three domains of technical, business, and human concerns.

Discussion

Engineering Education

Engineering education seems to have come under increased criticism lately, with many companies and students arguing that engineering curricula are too abstract and disconnected [5, 6]. It is interesting to reflect upon similar concerns of Henderson [7] and Grinter [8] dating back to 1983 and 1955. These studies consistently indicate that engineering education should have the following properties:

1. Relevance to the lives and careers of students, preparing them for a broad range of careers, as well as for lifelong learning involving both formal programs and hands-on experience;
2. Attractiveness so that the excitement and intellectual content of engineering will attract highly talented students with a wider variety of backgrounds and career interests—particularly women, underrepresented minorities and the disabled—and will empower them to succeed; and
3. Connectedness to the needs and issues of the broader community through integrated activities with other parts of the educational system, industry and government.

Plastics Engineering Education

For many years, our Plastics Engineering majors have enjoyed greater relevance in their studies than those studying traditional academic disciplines. As shown in Figure 1, plastics engineering departments have historically focused on balancing the theory and practice in three subjects [9]:

1. Materials: Understanding the composition and behavior of polymeric and composite materials in the solid and molten state;
2. Design: Understanding how the geometry of the product and tooling affects the part performance in end-use;
3. Processing: Understanding how the process dynamics and control convert low cost, raw material to high value, finished goods.

These subjects draw knowledge from a variety of traditional disciplines, including chemical engineering, materials science, mechanical engineering, and even electrical engineering. Students are required to possess a strong fundamental basis in mathematics, chemistry, and physics to understand the theory that is delivered in the courses and grounded in engineering practice.

The Current Curriculum

The current curriculum for the graduating class of 2006 is provided in Table 1. As shown, all freshman (declared and undeclared majors) will study calculus, chemistry, physics, writing, and introduction to engineering. Majors should be declared by the end of the freshman year, since sophomore level classes become specialized with the introduction of safety, materials, and processing courses specific to plastics engineering. Junior and senior level classes further develop the theory and practice of plastics engineering with respect to materials, design, and processing.

It is worthwhile to examine the composition of the curriculum. The rightmost column of Table 1 includes a breakdown of the credits for each course with respect to **F**undamentals, **M**aterials, **P**rocessing, and **D**esign. While not exact, this breakdown is intended to provide a close approximation of the type of topics taught in each course. For example, 26.373 Introduction to Mold Engineering is a three credit course that consists of 1 credit of fundamentals and 2 credits of design. While the majority of this course focuses on design of molds, 1 credit of fundamentals is allocated given the necessary analysis of costing, heat transfer, structural analysis, manufacturing, and material properties. A similar breakdown by topic is provided for all courses in the curriculum.

The estimated composition of the curriculum is provided in Figure 2. Given the authors' knowledge of the curriculum, the margin of error in this figure is rather small, on the order of a few percent. As shown, two-thirds of the curriculum is centered on providing fundamentals that are not specific to plastics engineering, but are requisite theory. The vast majority of these fundamentals are identical to what other engineering majors would also study, e.g. writing, calculus, chemistry, physics, thermodynamics, fluids, heat transfer, statics, dynamics, design, etc. As such, it is the remaining one-third of the curriculum on materials, processing, and design that differentiates the field of plastics engineering from other disciplines.

Competency Gaps

Mott et. al. [10] recently reflected on the state of various engineering technology programs relative to industry needs to remain competitive. Figure 3 depicts the competency gaps in manufacturing education. Their results indicate that the largest gaps are in communication, project management, problem solving, process technology and control, integrated product and process design, and several business topics.

For comparison, the authors have provided a similar analysis of the plastics engineering major in Figure 4. A comparison of Figures 3 and 4 indicates that plastics engineering is doing better than general engineering technology programs. Specifically, the accreditation process has demanded redressing communication and teamwork issues in our curriculum, which improves the performance of our students with respect to these topics. Moreover, our predominant focus on plastics allows our students to outperform with respect to manufacturing processing and integrated design.

Beyond the Technical Domain

Figure 4 indicates that our plastics engineering program could be improved in two areas. First, there is a lack of education with respect to business, project, & supply chain management. Second, there is a lack of focused specialization for personal growth. Such deficiencies in the curriculum may be a straightforward result of the academic training of the faculty, each of whom promotes their own area of specialization especially with respect to undergraduate electives, graduate courses, and new faculty hiring.

We admit that the majority of the courses provided in an engineering curriculum should deliver technical content necessary to provide the skills and knowledge to differentiate engineering students from the general populace. However, much of this technical content is provided in the abstract, without any context to human or business concerns. As such, the authors suggest that a plastics engineering education requires a curriculum that provides enrichment on technical, business, and human issues as shown in Figure 5. Moreover, plastics engineering should not be viewed as a final degree, but rather as an integral part of a purposeful program of lifelong learning across a career.

It is worthwhile to examine the composition of the curriculum with respect to these areas. The rightmost column of Table 1 also includes a breakdown of the credits for each course with respect to **T**echnical, **B**usiness, **H**uman, and **L**ifelong learning concerns. The results are provided in Figure 6. Approximately 80% of the curriculum is centered on technical issues, with only 7% directed to business issues, 10% devoted to human issues, and 5% related to lifelong learning. In fact, these small percentages are gross overstatements about the relative impact of the curriculum on the non-technical areas, since most of the non-technical courses are general education electives and are frequently chosen for ease of grading or scheduling. As such, graduating plastics engineers lack sophistication in theory and practice of business and human issues.

Recommendations

Given these reflections, several recommendations are made regarding the future directions for plastics engineering education. These recommendations are split between those within and outside academia's control.

Internal Recommendations

Learning-Centric Teaching: Research has shown that student learning is enhanced with the use of a consciously designed curriculum with courses that use activity-based teaching approaches [11]. The authors recommend the use of just-in-time delivery of theory driven by specific application to focused problems. For an extreme example, conductive and convective heat transfer might be better taught in the context of mold design. With respect to an integrated mold design and heat transfer course, it would be necessary to increase the number of credits for mold design, reduce the number of credits in traditional fundamental courses, and also coordinate the fundamental topics taught across multiple problem-specific courses. Such radical curriculum revisions are unlikely to be accepted or undertaken by the faculty of any existing engineering program. Yet, new engineering programs (e.g. Olin College) are taking such an approach. As such, perhaps a module-based approach that teaches fundamentals with applications is a starting point.

Lifelong Learning: The curriculum is designed so that a student may complete an undergraduate degree in eight semesters of full time study. However, many students do not manage to do so, for a variety of reasons including: academic difficulty, part time study, change in majors, coop work participation, and others. These low graduation rates should not be considered failings of the students, but rather indications that a full-time, four-year, traditional plastics engineering program may not be the best vehicle for satisfying industry or student needs. The authors recommend that plastics engineering programs be designed to encourage or at least allow balanced work-study programs. Specifically, several companies provide scholarships and internships to undergraduates that provide them financial remuneration with one year of practical experience while allowing them to graduate within four years….such programs should be encouraged. Alternatively, many students take a semester leave to work full time as a plastics engineer intern. The curriculum should be designed to allow such students to graduate in four years by taking summer courses in their freshman and/or sophomore years. Further, many students are returning or practicing veterans with ten to twenty years of experience in the plastics industry. For such people, some mechanism must be developed to account for their years of accumulated knowledge without being forced to take traditional and belittling academic courses…perhaps a modular curriculum with qualifying exams could enable such an objective.

Content Revision: The retrenchment of the plastics industry has provided clear indications that "best practices" must be continually improved in order to remain competitive. Similarly, the curriculum must be consistently revised to provide a relevant knowledge set that will serve the needs of the student and industry. There are two fundamental issues with respect to addition or deletion of content. First, the number of courses and credits in the curriculum must remain within the norm of engineering programs, lest students have to pay more time and money to graduate. These are strong disincentives to undertake a plastics engineering education. Second, there are many accreditation requirements that must be maintained even though they seemingly conflict with student and industry needs. Even so, the authors recommend that the content of the curriculum be consciously planned to address the competency gaps identified in Figure 4.

Additional content must be brought to bear on supply chain management issues, business strategy, ethics, and career development. The addition of these and other topics, however, must be carefully planned and implemented. For instance, the authors have contemplated the addition of a course in lean manufacturing and automation as a core requirement. Beall [12] suggests that U.S. processors have significant room for productivity gains through automated raw material handling, robotics for part removal, degating, and packing, as well as higher performance molding technologies. A similar argument [13] was made regarding the British plastics industry in a recent downturn. However, it is interesting to reflect that Asia already has the highest levels of automation in year 2000, as shown in Table 2 [14]. These data are strong evidence that automation alone will not provide competitive advantage to the United States processors. The authors thereby promote an integrated view in which the traditional technical content related to materials, processing, and design is applied to technical, business, and human domains.

External Recommendations

Professional Development: Plastics engineers must be considered an asset, not a cost. The best run companies actively promote employee development in the workplace, with one to two weeks of structured learning activity. The authors recommend that employers consider measuring their employees based on capability as well as contributions, and provide proactive programs for employee advancement. Moreover, the authors recommend that working professionals actively manage their career development, and objectively assess their skills relative to industry needs. Professionals should demand high quality development programs, and leave employers who do not promote internal employee development since such employers are likely to be the low cost suppliers and may not remain solvent given sustained overseas competition. Graduate education, in any field, must be considered at a strategic level, and consciously used for career growth.

Technology Development: The authors recommend that plastics engineering education, especially at the graduate level, be integrally tied to companies' strategic development of core competencies and advanced product offerings. University researchers are actively seeking interesting, difficult problems that may be outside the short-term and low-risk scope of many companies. As such, structured education and research agreements between industry and academe provide a mechanism for developing employees and products. Such relationships have been fostered within our own program, in which a company may provide equipment and funds for a laboratory or endowment in return for the delivery of specific technology development and course content. However, such multi-year agreements must be carefully structured to maintain funding and quality throughout their lifetime.

Fair Competitive Practices: The authors urge the International Trade Commission and Word Trade Organization to enforce a level playing field with respect to intellectual property, workplace labor, environmental regulations, and inequitable restrictive taxes. Unfair competitive practices undermine long term investment in employee and technology development, and directly reduce the size of the plastics industry and need for plastics engineering education.

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Table 1: 2006 Curriculum at Lowell

Semester	Course	Title	Credits (FMPD/TBHL)
1st: 17 Credits	25.107	Engineering I	2 (1001/1010)
	42.101	College Writing I	3 (3000/1011)
	84.121	Chemistry I*	3 (3000/3000)
	84.123	Chemistry I Lab	1 (1000/1000)
	92.131	Calculus I*	4 (4000/4000)
	95.141	Physics I*	3 (3000/3000)
	96.141	Fund. Exp. Physics I	1 (1000/1000)
2nd: 17 Credits	25.108	Engineering II	2 (2000/2000)
	42.102	College Writing II	3 (3000/1011)
	84.122	Chemistry II*	3 (3000/3000)
	84.124	Chemistry II Lab	1 (1000/1000)
	92.132	Calculus II*	4 (4000/4000)
	95.144	Physics II*	3 (3000/3000)
	96.144	Fund. Exp. Physics II	1 (1000/1000)
3rd: 17 Credits	26.001	Pl. Safety Lecture	0 (0000/0000)
	26.211	Eng. Mechanics	3 (1101/3000)
	26.201	Poly. Mat. I	3 (1200/3000)
	26.215	Pl. Proc. Eng. Lab I	1 (0010/1000)
	84.204	Intro. Org. Chem.& Lab	3 (2100/3000)
	92.231	Calculus B-III	4 (4000/4000)
	______	**Gen. Ed AH Elective	3 (3000/0021)
4th: 15 Credits	26.002	Pl. Safety Lecture	0 (0000/0000)
	26.202	Poly. Mat. II	3 (1200/3000)
	26.212	Part/Body Dynamics	1 (0001/1000)
	26.216	Pl. Proc. Eng. Lab II	1 (0010/1000)
	26.218	Intro. To Pl. Design	2 (1001/1100)
	26.220	Intro to Polymer Chem.	2 (1100/2000)
	26.247	Thermodynamics	3 (3000/3000)
	92.234	Differential Equations	3 (3000/3000)
5th: 16 Credits	26.001	Pl Safety Lecture	0 (0000/0000)
	26.301	Poly. Mat. III	3 (0300/3000)
	26.314	Fluid Flow	3 (2010/3000)
	26.315	Pl. Proc. Lab III	1 (0010/1000)
	26.377	Pl. Proc. Eng. I	3 (1020/2100)
	49.201	Economics	3 (3000/1200)
	______	**Gen Ed AH Elective	3 (3000/0021)
6th: 15 Credits	26.002	Pl. Safety Lecture	0 (0000/0000)
	26.306	Meth. Exp. Anal.	3 (1110/2100)
	26.316	Pl. Proc. Lab IV	1 (0010/1000)
	26.348	Heat Transfer	3 (3000/3000)
	26.373	Pl. Mold Eng.	3 (1002/2100)
	26.378	Pl. Proc. Eng. II	3 (1020/3000)
	84.339	Phys. Chem. Princ.	2 (2000/2000)
7th: 17 Credits	26.001	Pl. Safety Lecture	0 (0000/0000)
	26.403	Phys. Prop. Polymers	3 (1200/3000)
	26.404	Process Control	3 (2010/3000)
	26.415	Capstone Design I	1 (0001/1000)
	84.403	Int. Poly. Sci. I	3 (2100/3000)
	84.405	Polymer Lab I	1 (0100/1000)
	______	Design Tech. Elective	3 (1002/2100)
	______	**Gen Ed SS Elective	3 (3000/0021)
8th: 16 Credits	26.002	Pl. Safety Lecture	0 (0000/0000)
	26.406	Polymer Structure	3 (1200/3000)
	26.416	Capstone Design II	1 (0001/1000)
	26.418	Prod. Proc. Design	3 (0111/2100)
	______	**Gen Ed AH Elective	3 (3000/0021)
	______	**Gen ED SS Elective	3 (3000/0021)
	______	Tech. Elective	3 (0111/2100)

Table 2: Year 2000 Automation Level by Region

Location	IMMs	Robots	Estimated Ratio (%)
North America	6,900	1,960	28%
Europe	20,000	7,618	38%
Asia	19,500	9,212	47%
South America	2,600	330	13%
Africa	1,000	120	12%

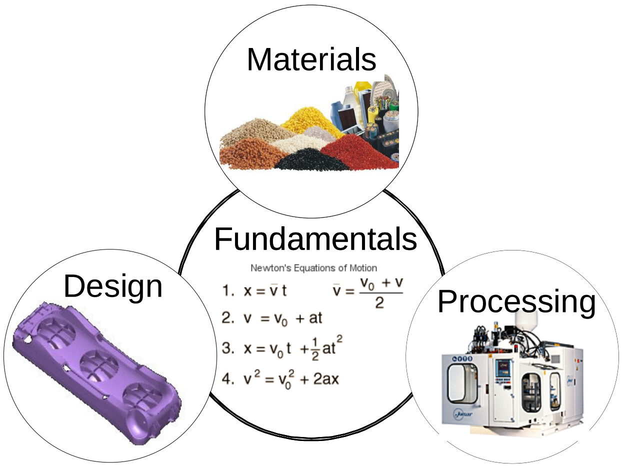

Figure 1: Traditional Plastics Engineering Domains

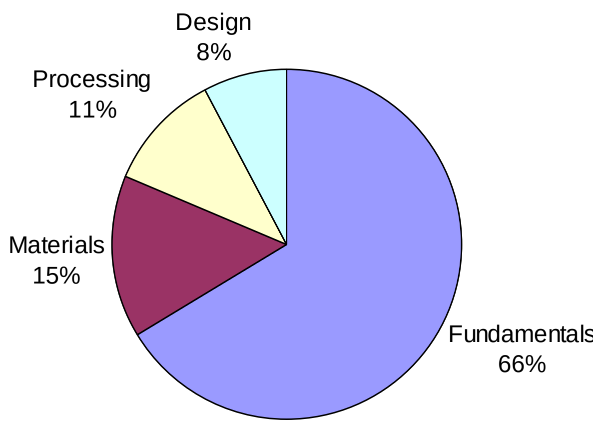

Figure 2: Technical Composition of Current Plastics Engineering Curriculum

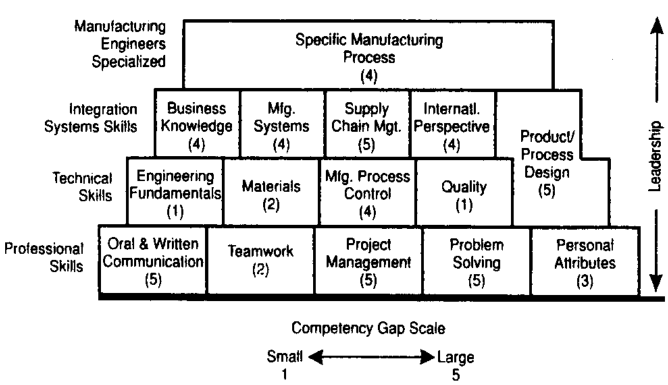

Figure 3: Manufacturing Engineering Competency Gaps [10]

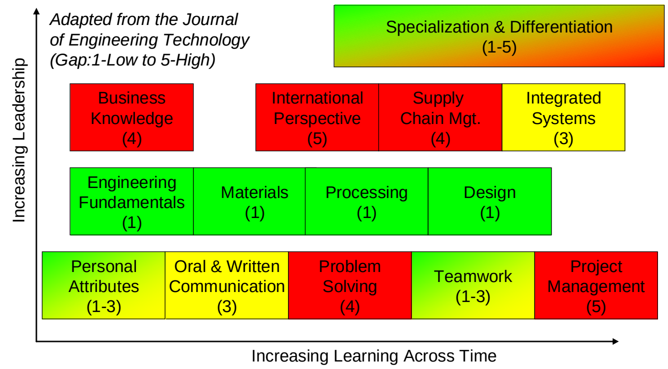

Figure 4: Competency Gaps of Current Plastics Engineering Curriculum

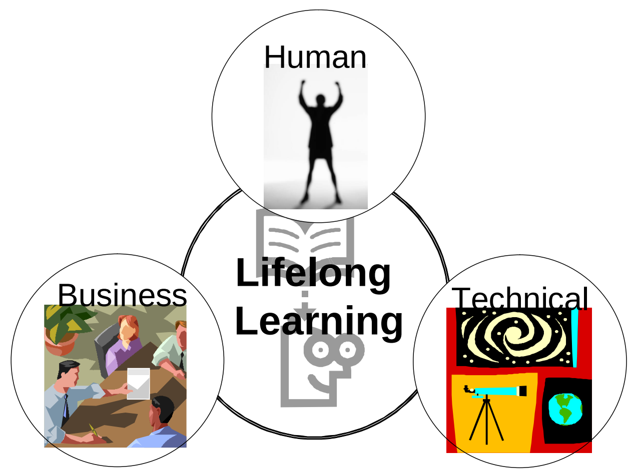

Figure 5: General Domains of Engineering Concerns

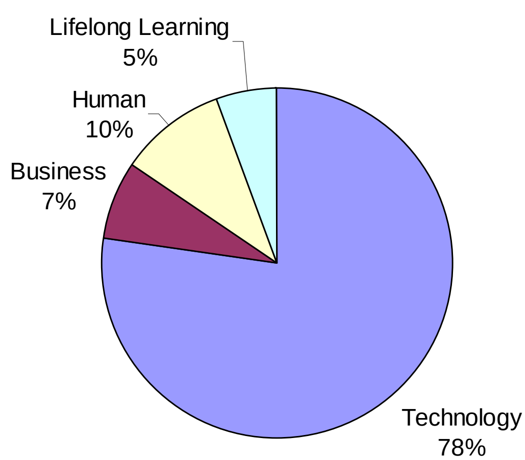

Figure 6: General Composition of Current Plastics Engineering Curriculum