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Systematic design, implementation and students perceptions of a polymer engineering course for chemical engineering curricula

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Original Research

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Abstract:

With rapid technological developments in the field of polymers, it became a necessity for the graduates in chemical engineering discipline to have a comprehensive understanding about the synthesis, properties, processing and product design fundamentals of various polymeric materials to excel in their imminent career fields. Many universities offer courses related to polymers as elective courses in the curricula of undergraduate programs in chemical engineering. The design aspects for the development of a core course in polymer engineering for undergraduate chemical engineering program is presented in this paper. The students' feedback on the newly designed course were also analyzed. The systematic design described here agrees well with the outcome-based education approach promoted by most of the accrediting bodies around the world.

Keywords: Course design; Polymer engineering core course; Chemical engineering curricula; Learning outcomes; Student perceptions

1. Introduction

Recently, graduate students associated with the University of Michigan's Macromolecular Science and Engineering Program have developed teaching modules to improve the accessibility of polymer education material [1]. These modules are designed in such a way as to enable the polymer topics to be taught at grades 1-12, so that greater awareness will be there among school graduates about the science and technology of polymers. Lately, researchers from British Columbia Institute of Technology have designed polymer science modules for educating post-secondary students from different disciplines [2]. The 20th century witnessed the emergence of technology of polymers soon after the hypothesis of macromolecules was introduced by Staudinger in 1920 [3]. Polymers entered in to all aspects of our life replacing the conventional materials such as metals and wood and it was considered as a revolution. With a century of research and development activities, polymers entrenched in to almost all application areas starting from commodity materials to construction, automobile, aerospace, electronics, information technology, medical devices, drug delivery and so on. Majority of the chemical engineering graduates will come across the area of polymers during some point of time in their career irrespective of the nature of their work, whether in production, research and development (R&D), design or marketing [4]. When it comes to chemistry graduates, more than half of them work with polymers during

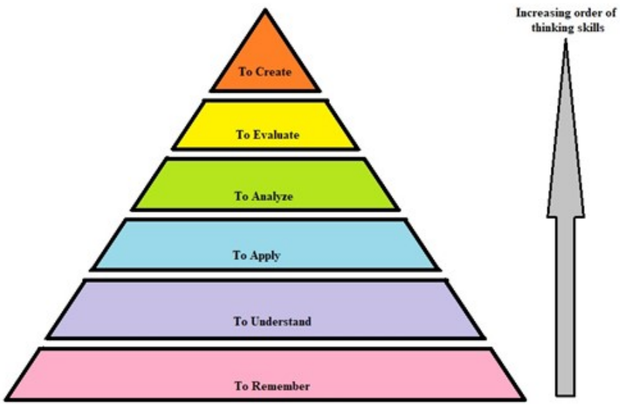

Figure 1. Learning domains according to increasing order of thinking.

their profession [5]. As this is the fact, the chemical engineering graduates must have an understanding about the polymers and their technological aspects.
Even though the technology of polymers find rapid growth in various application sectors, the area as an educational stream is still understated in many of the educational curricula all over the world [6]. Modest attempts to incorporate topics related to polymers in the engineering curriculum evolved in the second half of 20th century [7]. During 1980, universities around the world earnestly started introducing polymer course components in their conventional programs' curricula including that of chemical engineering. Even then, this was limited to approximately 75% of the institutions, and about 25% of the chemical engineering departments did not have at least one course on polymers in their curricula [8]. The chemical engineering core course subcommittee of American Chemical Society (ACS) during 1980-1982 identified and elaborated four major areas in the curricula where polymer related course components can be integrated. These were i) introductory chemical engineering, ii) transport phenomena and unit operations, iii) chemical engineering thermodynamics and iv) reaction engineering [4]. The surveys conducted by the education division of American Institute of Chemical Engineers (AIChE) during 1980s revealed that polymers are offered as an elective course in less than 13% of the institutions that participated in these surveys. Even in the 21st century, very few universities offer courses in polymer science [9]. As per the latest survey conducted by AIChE education division in 2014, polymers continues to be the most widely offered electives in most of the schools offering chemical engineering programs [10]. Martina and Christopher presented a modular approach in design of a polymer science elective course for chemical engineers [11]. Elective courses are defined as courses offered by the departments that may be voluntarily selected by the students, but not specifically required for their graduation, unlike a core course. Most of the academic accreditation agencies including Accreditation Board for Engineering and Technology (ABET) specifies the importance of incorporating courses in the curricula that prepares the students for the increasingly complex technical specialties later in their career. Such courses are expected to develop student competency in the taught discipline and prepare students for a career, further study, and lifelong professional development [12]. A recent report applied project based learning technologies in a materials laboratory atmosphere related to mechanical and chemical engineering students and students were of the opinion that the acquired skills and knowledge were helpful to them to achieve higher order thinking [13]. Another recent report on the modernization of the chemical engineering education in Brazil based on polymer reaction engineering setup revealed interesting results such as improvements in soft skills, communication ability, team work and critical thinking could be brought out by small changes in the learning activities [14]. A recent paper studied new-product creativity (NPC) through the engineering design process (EDP) for polymer engineering students through the polymer-processing laboratory course [15]. Two groups of students were utilized as one batch with experimental and the second group with theory only. The first group was motivated to learn the engineering topics in a better way than the second group. The experimental results showed that the students who learned with NPC-EDP had better higher-order thinking skills (HOTs) in the polymer-processing laboratory course than those who learned with conventional learning.
There are no recent reports on the design and implementation of a core polymer course for the undergraduate chemical engineering stream. In this article, we describe a systematic design of a core course in polymer engineering for undergraduate students in chemical engineering.

2. Methodology

A systematic course design starts with the identification of the needs. Students, faculty, employers and recent graduates are considered as the key constituencies in any academic programs [16]. A survey among the key constituencies is the starting point for the development of a new course or modification of the existing course in a curriculum as it clearly provides an idea about the expectations of the stakeholders about the knowledge and skill set imparted to the graduates upon successful completion of the course or the program [17]. Sometimes, the requirements of specialized local industries play a key role in the development of new courses or programs. This in turn improves the employability of the graduates. The five major aspects of a course

Table 1. Typical learning outcomes and their respective learning domains for the course.

learning outcomes	learning domains
outline the basic molecular structure of common polymers and relate it to the synthesis routes	to remember/understand
describe the physical morphology of polymer materials and relate this to relevant features of the chemical structure of the polymer	to understand
interpret data from polymer testing and apply this to solving problems encountered in polymer applications	to apply
describe the basic mechanical behavior of polymers and correlate with the chemical and physical structure of the material	to apply
choose the appropriate processing methods for making common articles and the basic characteristics of the polymer required for such operations	to apply
apply the knowledge of polymer properties and polymer processing in evaluating and selecting suitable polymers for engineering applications	to evaluate
understand the importance of minimizing the impact on the environment by creating ideas for responsible use and recycling of polymers	to create

design are [18].

- Developing the aims and objectives
- Shaping the structure of the course
- Finalizing the content
- Framing the evaluation and learning-teaching strategies
- Categorizing the knowledge and skills that students will be expected to possess at the end of the course

3. Aims and objectives

The first step in successful design of a course is to clearly define the aims and objectives of the course. It is also known as course description in another terminology. This provides a quick snapshot about the benefits of learning a particular course. Aims are considered as long-term targets and objectives are seen as nearer targets [19]. A typical course description statement can be as follows:
”*This course describes the introduction to polymer science and engineering, mechanisms of polymerization, various polymerization and characterization techniques. Various polymer processing operations and the equipment involved are discussed. Fundamentals of structure-property relationships in polymeric materials, rheology of polymers, mechanical and thermal properties of polymers and product design aspects are also introduced. The impact of polymers on the environment and the recycling options are also mentioned. The topics are supplemented by relevant laboratory experiments*”
There are different arguments to differentiate between course objectives and course learning outcomes. Some researchers are of the opinion that “learning outcome” is simply an alternative name for “course objective” [20]. Other argument is that there are some major differences between these two, where the level of specification is emphasized [21]. Richard S. Ascough of Queen’s University mentioned another way for differentiating course objectives with learning outcomes. It says “objectives are what the instructor intends for the learning in a particular course and outcomes are how the student demonstrates learning in the course” [22]. In the modern era of outcome based learning approach, a clear understanding of the learning outcomes is very much essential to realize the level of the course or the depth of knowledge imparted to the learners through the course. Course objectives or the course learning outcomes describes what knowledge and skills the learner is expected to possess at any specific point of time during the course or upon successful completion of the course [23]. While setting the learning outcomes in the new era of outcome based education system, the students perceptions about the changing technological developments and the associated learning environments also must be taken in to consideration [24]. Clearly designed set of learning outcomes help to formulate suitable instructional strategies and help to frame suitable assessment methods to evaluate the extent to which these outcomes are achieved by the students in their true sense [25]. Widely discussed Bloom’s taxonomy [26] and its revisions [27, 28] provide a clear set of guidelines for setting learning outcomes, formulating the teaching strategies and the assessment and evaluation of the effectiveness of the overall teaching-learning process. The newly developed developmental teaching and learning (DTL) strategy envisages that “educators’ main goal is not to have their students accumulate information (which inevitably soon gets outdated anyway) but to help students develop their minds (thinking and problem solving) in specific areas-their “mathematical minds”, their “historical minds”, their “linguistic minds”, their “social minds”, and so on-so that students continue to enhance their abilities to make sense of various scientific phenomena and social events and, most importantly, of their own lives” [29]. Accordingly, a course must have 6 different cognitive domains and they can be arranged in the increasing order of intellectual complexity as shown in Fig. 1.
Considering all these aspects, typical course learning outcomes for an undergraduate polymer engineering course for chemical engineering curricula can be designed as given in Table 1.

4. Structure of the course

Having formulated the aims and learning objectives, the next step is to decide the structure of the course. Typically, an undergraduate course offered within a semester is distributed to 15 instructional weeks. As the course on polymer engineering requires the demonstration as well as hands on experience with machineries and equipment, an integrated laboratory session is highly advisable. A typical 4 credit course comprise of 3 hours of lecturing and one session (3 hours) of laboratory experience in a week.

4.1 Contents, teaching-learning strategy and evaluation

The contents of a course make sure that the course clearly fits in to the curriculum. Often the pre-requisites or the prior knowledge that the students gathered from previous courses are highly important in finalizing the contents of a course. The survey among the constituencies, mainly the stake holders from industry, helps very much to decide and finalize the course contents to up-to-date. Based on the hierarchy of the listed learning outcomes, the major content of the course can be developed based on the available instructional weeks and time. Selection of a well written text book/books based on the content of a course is also helpful. Students generally keep good text books as reference books for many years in their career. But caution must be exercised as text books can escalate or diminish the quality of an offered course [30]. A typical course content for the course can be outlined below; *Introduction to Polymers, Polymer Synthesis, Polymerization Techniques, Structure-Property Relationships in Polymers, Characterization of Chain Microstructure, Viscoelasticity and Rheology of Polymers, Polymer Processing Operations, Polymer Product Design Aspects, Environmental Aspects*
Textbook of Polymer Science by Fred W Billmeyer, Essentials of Polymer Science and Engineering by Paul C. Painter, Michael M. Coleman and Polymer Science: A Textbook for Engineers and Technologists by Sebastião V. Canevarolo are the suggested text books to cover the contents mentioned above. Some useful reference books are Polymer Handbook, 2 Volumes Set, 4th Edition, J. Brandrup (Editor), E. H. Immergut (Editor), E. A. Grulke (Editor), Principles of Polymer Chemistry, Paul J Flory, Handbook of Plastics Testing and Failure Analysis, Third Edition, Vishu Shah and Principles of Polymer Processing, 2nd Edition - Zehev Tadmor, Costas G. Gogos
Pre-requisites are considered as an important factor while designing a new course. There exist a significant relationship between students' performance in a particular course and the knowledge gathered from pre-requisite courses [31]. Organic Chemistry and Materials Science and engineering courses, which are generally included in all Chemical engineering curricula can be considered as the pre-requisites for this course. Third year of the program will be ideal to offer such a course in the Chemical engineering curriculum to comply with the pre-requisites requirements.
Laboratories are considered as an essential component of undergraduate studies and most engineering instruction take place in the laboratory. Engineering students go to an instructional laboratory to learn something that practicing engineers are assumed to know already [32]. Laboratory experiments help to reinforce the course contents mentioned in the theory section and also provide hands on experience to the students. This is also part of learning by doing strategy in the active learning methodology. Hands-on laboratory experiments are critical to understand the properties of materials and their structure-property relationships even though the concepts can be translated through lecture courses. Carefully designed laboratory experiments enable the students to ask "what if" type of questions thereby transforming the classic laboratory demonstrations into inquiry based learning experiences [33]. The set of experiments that are necessary to reinforce the contents of a polymer engineering course are given in Table 2.
The teaching-learning strategies witnessed a rapid change

Table 2. Laboratory exercises for a polymer engineering course.

exercises	title of the experiment
1	safety and orientation for a Polymer Engineering Laboratory
2	synthesis of Polymers in the Laboratory Part-I Preparation of Polystyrene
3	synthesis of Polymers in the Laboratory Part-II Preparation of Nylon 6,6
4	dilute Solution Viscometry
5	identification of polymer structure by using Infrared Spectrometer
6	determination of Melt Flow Index (MFI) of Polymers
7	determination of Apparent Viscosity of Polymers by Torque Rheometry
8	compounding of polymers by using a batch melt mixer
9	preparation of Test Specimens by Injection Molding and Specimen Cutting Press
10	determination of Viscoelastic Properties of Polymers by Capillary Rheometer
11	determination of Mechanical Properties of Polymers by Universal Testing Machine
12	determination of Thermal Properties of Polymers-I Differential Scanning Calorimetry (DSC)
13	determination of Thermal Properties of Polymers-II Thermogravimetric Analysis (TGA)

in the last few years with the development of student-centered learning in educational instruction. In the recent past, there has been a change from the conventional chalk and talk strategy to active learning methodologies such as problem based learning or project based learning [34]. The project-based learning strategies can be very well integrated to a course on polymer engineering and the examples of some projects that can be assigned to the students are given below [35–37];

1. Prepare Polystyrene (PS) and Nylon 6, 6 by suitable

polymerization methods and determine their molecular weight and melt flow related properties.

2. Incorporate a nano-filler in to these polymers (PS and Nylon 6,6) (10 wt%) and explore the rheological characteristics of the prepared polymer compounds.

3. Determine the mechanical, thermal, optical, electrical and barrier properties of the filled and virgin polymers from the above 2 projects.

4. Select suitable polymers for some of the given applications based on available properties from projects 1, 2 and 3 above.

5. Review various strategies to address the environmental problems created by waste plastics and suggest some innovative techniques with details.

6. Design a plant for waste plastic recycling for a given capacity and calculate the overall energy requirements and cost.

7. Simulation of Polyethylene production process.

Student groups can be assigned with these projects and the groups can present their strategies, experimental results and the underlying principles/knowledge components to the whole class or even to the junior batch of students, thereby boosting their interest toward the course [38]. Such exercises help the undergraduate students to deeply understand various topics in the course, thereby enhance their knowledge and skill sets and leads to enhanced employability. The other teaching strategies that can be adopted to disseminate various contents of this course are; class room interactive sessions, group activities and discussions, brainstorming sessions and student presentations in the class in addition to the planned laboratory exercises.
Assessments play an important role in effective education. Well planned and executed assessments can contribute valuable information to the instructors with data they can use to move the field forward [39]. There are two types of assessments, formative and summative. Formative assessment is defined as "activities undertaken by teachers and by their students in assessing themselves that provide information to be used as feedback to modify teaching and learning activities" [40]. Thus, formative assessments are valuable piece of feedback for both the students and the instructors to assess their learning and teaching strategies and progress. Summative assessments on the other hand are the cumulative of all the assessments during the course of study, which is used to assess the quality of the learning and judge the performance of students against some established standards such as grading system [41]. Various class assignments, unit tests, evaluation of laboratory performance, group activities and mid-terminal examinations are considered as formative while cumulative of all these assessments along with final theory and laboratory examinations are considered for summative assessments to decide the final grade of a student in the course. Many of the course contents can be taught as self-learning topics and writing to learn assignments (WTL). WTL is a promising active learning methodology as it supports deep conceptual learning [42]. A typical distribution of weightage for all the assessment components are given in Table 3.

Table 3. Assessment components and their weightages.

Assessment components/category	Weightage (%)
Quizzes at the end of each module (formative)	5
Homework assignments (formative)	5
Group activities (formative)	5
Mid terminal exam (theory) (formative)	10
Mid terminal exam (laboratory) (formative)	10
Laboratory performance and reports (formative)	5
Final lab examination (summative)	20
Final theory examination (summative)	40

4.2 Categorizing the knowledge, skills and competencies

Finally, the design of a course can be considered as complete, only after listing the knowledge, skill sets and competencies disseminated to the learners. Mapping of each individual modules and learning outcomes of a course against the respective learning domains is mandatory as per the accreditation criteria of many agencies including National Assessment and Accreditation Council (NAAC), ABET, the Accreditation Agency for Study Programs in Engineering, Informatics, Natural Sciences and Mathematics (ASIIN) and European Qualifications Framework (EQF). A core course in Polymer Engineering is expected to impart the following knowledge and skills to the students;

- Polymer synthesis (knowledge)
- Structure-property relationships in polymers (knowledge)
- Interpretation of data from various tests (skill)
- Solve problems encountered in application of polymers (skill/competency)
- Understand appropriate processing techniques and their unit operations (knowledge/skill)
- Select suitable polymers for various engineering applications (skill)
- Understand the importance of recycling and minimizing the impact on the environment (competency)

Table 4. Student perceptions and feedback on the newly introduced course.

Statements in the survey	**Student responses (% for each)**				
	1	**2**	**3**	**4**	**5**
The course Polymer Engineering was well organized and helped me to understand the underlying concepts very well				38.5	61.5
The instructional materials (Reference books, handouts, PowerPoint presentations, lab manual) increased my knowledge and skills in the subject matter			7.7	46.2	46.2
The lectures, lab exercises, quizzes and assignments complemented each other				7.7	92.3
The course assignments facilitated my learning				23.1	76.9
The laboratory exercises helped me to understand the theory topics in a better way				23.1	76.9
The assessments and examinations measured my knowledge in the course				38.5	61.5
The course triggered my critical thinking as an Engineer				38.5	61.5
I believe that what I have learned in this course will help me in my future career				15.4	84.6
The course gave me the confidence to take up challenges and to do more advanced work in the field of Polymers			7.7	30.8	61.5
I would like to pursue my higher studies in the field of Polymer Engineering if I get a chance	7.7		7.7	23.1	61.5
Overall, Polymer Engineering course met my expectations for the quality of the courses in my BS program			15.4	23.1	61.5
I would highly recommend this course to other students				23.1	76.9

5. Student perceptions, satisfaction and motivation

Understanding and analyzing the students' perceptions, their motivation and satisfaction level with respect to the course content and the instructional strategies are very important in implementation and future modification of a course. student satisfaction is related to clear communication and clarity of the course learning objectives, selection and use of appropriate course materials, effective instructional strategies that support the learners to digest the course contents and timely feedback on formative assessment components [43].

The newly developed course was successfully offered for two consecutive semesters and at the end of the semester students were provided with a survey questionnaire on the effectiveness and quality of the course and on the level of students' satisfaction of the course. The students were directed to express their feedback on a scale of 1–5, with 5 representing "strongly agree" to the statements, 4 stands for "agree", 3 stands for "neither agree nor disagree", 2 for "disagree", and 1 for "strongly disagree" with the statement. The anonymous survey was conducted through Google Survey platform. Even though the total number of participants was 50, the perceptions of the students related to the course contents and their overall feedback about the course can be considered as a valuable information for future modifications or improvements in the course. A summary of the students' feedback is given in Table 4.

The survey results are encouraging. The analysis of the student response indicate that they have accepted the new course enthusiastically and most importantly they are satisfied with the instructional components of the course. Most interesting points are that, they have a belief that what they learned through the course will have a positive impact in their career and they would like to pursue higher studies in the field if they get a chance.

6. Conclusion

It has been demonstrated how a systematic approach could be applied to design of a course in polymer engineering for the undergraduate students pursuing chemical engineering curricula. The proposed logical course design helps the educators in the field to introduce this course which is optimized with respect to the students' learning efficiency and overall workload during a taught semester. The needs of the labor market form the main driving factor in design of the major components of the course, while proper balance of the knowledge, skills and competencies is very much essential to align the course learning outcomes with the learning outcomes of the main program. A balanced set of courses that address all major fields or areas under the chemical engineering stream is essential to expand the employability of the graduates. In this way, the guidelines set forth by the accreditation agencies, in training the students for the increasingly complex technical specialties and associated career fields later in their profession, can also be achieved.

Ethical Approval
This manuscript does not report on or involve the use of any animal or human data or tissue. So the ethical approval does not applicable.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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