Undergraduate Labs in Applied Polymer Science – A Case Study

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Abstract

Undergraduates majoring in Packaging Science at Clemson University are required to take a combined lecture/laboratory course in Application of Polymers in Packaging in their junior or senior year. Over four semesters, the focus of the laboratory portion of the course has been transitioned from polymer processing to understanding basic process-structure-property relationships in polymers. Using new thermal analysis equipment funded by an NSF CCLI grant, students working cooperatively in small teams have been engaged in series of laboratory exercises from which they are required to formulate hypotheses and conclusions to relate observed properties to process variables by understanding the molecular structural changes that have occurred. The grant has also enabled each of the experimental laboratories to be updated and synchronized with the classroom lessons. Using student surveys and semester-to-semester comparisons of performance on specific final exam questions, the grant team has found that student motivation, involvement and achievement are enhanced by coordinated timing of classroom and lab topics, structured three-member lab teams and apparently simple experiments that challenge the students to work cooperatively in their teams to find scientifically valid explanations for their data.

Background

The Packaging Science program at Clemson University is currently the only program in the Southeast, and one of only four in the United States, that offers a four-year curriculum leading to a B.S. degree in Packaging Science. It stresses the scientific and technological aspects of packaging. Requirements for graduation include biology, chemistry, physics, polymer science, mathematics, graphics, statistics and microbiology, in addition to basic humanities and social sciences. There are 13 core packaging courses, four of which are taught as laboratories. Each of these three lab courses is accompanied by a lecture for which the students must register separately. Several of the other courses are taught as lab/lecture combinations. All students must also complete a 15- to 24-week co-op assignment in industry as a requirement for graduation.

In March 2001, a group of three Packaging Science faculty received an NSF CCLI grant to adapt materials characterization techniques to collaborative, discovery-based learning in the undergraduate Packaging Science curriculum. The major objectives of this project are:

- To incorporate more science-based learning in our Packaging Science laboratory courses
- To significantly increase the understanding and hands-on experience of our undergraduate students with state-of-the-art materials science characterization and investigative techniques as applied to Packaging Science
- To redesign our laboratory courses to maximize collaborative, discovery-based learning.

These funds enabled the purchase of thermal analysis equipment, including modules for DSC (Differential Scanning Calorimetry) and TMA (Thermal Mechanical Analysis).

The author and his colleagues in the Packaging Science Department decided to focus the initial efforts of the project on the core curriculum course, Application of Polymers in Packaging, which is offered to juniors and seniors. Also available to support these efforts in addition to the new thermal analysis equipment was an upgraded tensile testing machine, newly equipped with current generation software and a furnace for elevated temperature testing. The work will be extended to two sophomore-level courses in the second year of the grant and to one other advanced course in the third year.

The author had already completed a major revision of the structure of the lectures to emphasize a basic understanding of polymer structure and behavior that could be related to processing and properties. Major sections covering polymer structure and viscoelasticity were added to the sections covering extrusion, film-making, thermoforming and bottle blowing, while polymer chemistry and polymerization processes were de-emphasized. This was considered more appropriate for graduates who were universally polymer users rather than polymer manufacturers.

Due to a lack of equipment alternatives, the old laboratory structure was maintained. The labs focused on polymer processing using very old bench scale apparatus for demonstrating thermoforming, injection, blow and rotational molding, and glass-reinforced thermosetting polyester molding. The students were able to make small parts, such as screwdriver handles that bore no relation to packaging. The most appealing lab utilized the department's Killion extrusion apparatus to demonstrate either cast or blown polyethylene film (alternate years). Here the students had the challenge to try to optimize the process conditions.

<u>Revision of the Laboratories</u>

The new thermal analysis and tensile testing equipment provided the route to totally revising the laboratories to enhance and support the basic course curriculum. In addition, updated versions of the bench scale processing equipment were purchased, including packaging related molds. The objectives developed to guide the revision were:

(1) Each lab exercise should relate to packaging;
(2) Each lab exercise should demonstrate or illustrate at least one key learning objective covered in the lectures and reading;
(3) Each lab exercise should offer students the challenge to relate a structural parameter to processing and/or properties;
(4) Each lab exercise should challenge the students to explain an unexpected result;
(5) During the semester, the students should work with all three categories of polymers important to packaging--amorphous, crystalline and crystallizable.

Over the past three semesters, the labs have evolved to five main units that require nine or ten two- to three-hour-long laboratory sessions to complete. These units are:

Thermoforming of polyester sheets - Students find optimum conditions for thermoforming a non-crystallizable and a crystallizable polyester sheet. Using DSC, students can relate the thermoforming window to the crystallization behavior. The unexpected result is that one sheet turns hazy if the temperature is too high.

Hot filling of polyester bottles - Students measure the volume shrinkage resulting from filling several different polyester bottles with hot water. They compare the weight and design of the bottles. Using TMA measurements of shrinkage and DSC measurements of crystallinity they relate the results to the structure and processing history of the bottles. The challenges are that one of the bottles is multi-layer and that each type of bottle is made with a different copolymer.

Structure-property-process relationships of cast polyethylene films - Students help produce cast polyethylene films using four different casting conditions, basically a small designed experiment, noting the changes in film appearance as the conditions change. They measure the stress-strain properties of the films lengthwise and cross-wise and characterize the crystallization behavior with DSC. The challenge is that the machine and cross direction properties change in unexpected ways.

Measuring and using time-temperature superposition - Students measure the stress relaxation of an amorphous polymer below, at and above the glass transition temperature to learn the procedures for collecting and analyzing these types of data. They then used much more detailed data supplied by the instructor to construct a master curve and apply it to solve a practical problem in long term storage of a package.

Processing of polymers - Using bench scale equipment, sudents extrusion-blow-mold a small polyethylene bottle and injection mold a screw cap to fit. They learn to measure Melt Index and relate it to molecular weight. They make blown polyethylene film and learn how difficult it is to stabilize the bubble to get uniform film.

Collaborative Learning in Teams

Collaborative (sometimes referred to as cooperative) learning is defined as "a structured, systematic instructional strategy in which small groups of students work together towards a common goal." [1] We have taken a number of steps to take advantage of the guidance provided in the literature[1-7] for structuring cooperative teams.

We assign the students to small (typically three students) teams, in which they work the entire semester. The team members are assigned by the instructor to ensure diversity, and an approximately even distribution of GPA's and of students who have completed their co-op assignments.

The teams are instructed to ensure that each student participates as equally as possible in both the experimental and the writing work of the team. According to a pre-determined schedule, each team submits a full laboratory report for each of the five lab units. The report due dates are assigned so that all of the material required to understand the lab unit has been covered in class prior to the due date. Each team member receives a team grade based on the report. Scientific content, organization and writing elements are all graded. The teams organize their own work and meeting times. They are however cautioned that no one member should be assigned to write all of one report.

To ensure individual accountability, each student is required to keep his own laboratory notebook using generally accepted industry standards for research notebooks. Each student receives an individual grade for neatness and completeness of his notebook. During labs, note-taking on loose pads is not allowed.

The experimental portion of the lab units is primarily problem-based learning. After one semester of attempting to let the teams structure their labs based on a set of questions posed by the instructor, it was apparent that the students did not have the background to construct a lab unit on their own to meet the learning objectives. The analysis and writing portion of the lab units is, however, highly discovery-based. The students must analyze all of the data collected and provided and synthesize a discussion and explanation based on lessons in the classroom and additional literature research. The "unexpected results" built into most of the labs challenge the teams to truly work cooperatively to discover a rational explanation.

<u>Technology Enhanced Learning.</u>

Clemson University has a highly developed on-line collaborative learning environment. All lectures and supplemental materials are accessible on-line via the Internet. Students turn in all work on line. The lab write-ups have required students to use Excel and other data analysis and charting programs to digitize their information. Many teams also used digital cameras and scanners to capture and convey their data and reports. The instructor uses the editing functions in MS Word to review and edit the reports. They are then returned to the students' on-line folders.

<u>Other Findings and Issues</u>

By the third semester, it was apparent that a team size of three was optimum both to allow equal participation in the laboratory and to facilitate meeting outside of class to discuss and prepare the analyses and reports. Students were told to seek the instructor's help if a student was not participating. This happened only once in three semesters.

Because there is only one of each type of equipment, the teams have to be divided into laboratory sections of twelve and the lab units scheduled in rotation. The challenge is to create a schedule that allows teams to complete lab units spread throughout the semester. Students do not look favorably on a situation that makes too many assignments due at the end of the semester. Equally challenging is to coordinate the labs with the lecture sequence. Although it is impossible for the students to have the complete background for each lab before doing it, it has proven possible to schedule the reports after the material has been covered.

Ideally, each team should analyze its own data for each lab. In practice this has proven impractical. The students are capable of analyzing much more data than they can collect in the relatively short laboratory period. Also, little additional learning takes place waiting for the DSC to go through one temperature cycle after another. In the current semester, we will therefore assign the students representative data to collect to give them hands on experience with each type of equipment. The complete set of data will be collected by the instructor and his TA and provided to the teams. This also means each team will analyze the same data, which have been reviewed for internal consistency.

<u>Student Responses</u>

Student response to the changes in the laboratories has been measured in two ways. 1) Final exam answers over three semesters on three questions directly related to the laboratories have been compared. 2) Anonymous surveys about the laboratories were collected at the end of the Fall 2001 semester, and, for comparison, solicited from students still on campus who had competed the course in the Spring 2001 semester.

Table I shows the results of the final exam question comparison. The new labs were partially introduced in Spring 2001 and fully introduced in Fall 2001. The data indicate that the new labs especially benefited the C students. A and B students showed a significant improvement semester to semester on only one of the three questions, while students scoring C and lower on the overall exam, showed significant improvement in all three questions related to the labs.

Table I									
Final Exam Question Comparison (exam or question grade - %)									
	Full Class			A & B			C or lower		
	F 2000	S 2001	F 2001	F 2000	S 2001	F 2001	F 2000	S 2001	F 2001
Number of students	20	28	12	7	12	8	13	16	4
Final exam average	74%	73%	83%	85%	88%	89%	68%	61%	72%
Question 1	72%	88%	96%	86%	100%	100%	65%	78%	88%
Question 2		47%	58%		65%	66%		34%	42%
Question 3		49%	75%		55%	78%		45%	69%

All twelve students taking the class in Fall 2001 completed a survey of eighteen questions. These questions covered enjoyment and motivation (2 questions), personal involvement (2), learning (7), and team functioning (7). The students' responses were very positive. They felt involved (8.8/10); they felt the labs contributed greatly to their understanding of the course (7.0/10); the teams functioned well in both doing (8.4/10) and writing up (7.8/10) the labs; the teams had constructive discussions while doing and writing up the labs (8.2/10); and students felt that working in a team rather than individually helped their understanding of the labs (8.0/10). Only one out of the four teams reported that one or two team members did most of the work. Similar surveys will be used to track response over the next several semesters.

Future Work

The author will continue to develop the applied polymer laboratories discussed here, especially as additional characterization equipment becomes available. Students who have graduated and entered the workplace will be surveyed to assess the effectiveness of the changes that have been made and to identify additional needs. Introductory thermal analysis will be introduced into the sophomore level courses. Also, some of the processing will be moved back to the sophomore level to allow more time at the advanced level for more materials science oriented work. The experience with discovery-based, cooperative team learning will also be extended to the sophomore level courses and eventually to the other laboratory courses in the Department.

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