”Let’s Find Out”

Dr. Irina Molodetsky, New Jersey Institute of Technology

Irina Molodetsky, PhD, joined Otto H.York Department of Chemical and Materials Engineering in the summer of 2017 as a Senior University Lecturer, New Jersey Institute of Technology NJIT). She received her BS, MS in Physics from Odessa State University, Ukraine and PhD from Princeton University. She was a Materials Scientist at Princeton Technology Center, Schlumberger. Irina has experience in R&E, as well as manufacturing technologies for nuclear tools developed for oil and gas exploration. As a Principal Materials Scientist she led a Neutron Generators technology team. At NJIT, she truly enjoys teaching undergraduates and extensively uses her industrial experience for designing real life laboratory experiment challenges and projects for students; develops courses for a new Materials Engineering Program (started in Fall 2022), currently teaches Mechanical Behavior of Materials and Electrical, Optical, Magnetic and Thermal Properties of Materials (EOMT). She continuous teaching Chemical Engineering Laboratory for Seniors and other undergraduate classes at Materials and Chemical Engineering Department.

Let’s Find Out

Introduction

This paper is focused on the methodology to inspire students to have an earnest aspiration for experiential learning [1] and to introduce them to new materials characterization techniques through a balanced combination of project-based learning (PBL)[2] and project-led education (PLE)[3]. The PBL methodology is widely adopted, researched, assessed, and continuously adjusted to new realities and societal inquiries [4-6]. The method was expanded and reviewed with an emphasis on the development and acquisition of learning, experimental, and communication skills, practical dimensions of learning, and relevance to the society in which the students live [7-9]. Here, the adoption of a balanced combination of PBL and PLE was motivated by challenges associated with introducing a new baccalaureate program in Materials Science and Engineering (MSE) at NJIT. It was desired to achieve three goals while teaching a small inaugural class of MSE students:

- To develop consistent interest and curiosity of students about the subject matter.
- To offer repeated cross-references to different aspects of the course material to reinforce their newly acquired knowledge.
- To facilitate connections between this course material and broader topics included in the curriculum to which the students will be exposed during their undergraduate studies.

The approach to meet the 1st goal is to involve the students in the process of identifying and developing their own question or problem for a project. The second goal is achieved with a widely used discussion-based class format. The approach to reach the third goal is to guide the student project to ensure that the students become exposed to materials characterization techniques or methods that may not have been covered in this class but will be included in the subsequent curriculum. An implicit overarching goal was also to make the new MSE program known as interesting and fun to a broader student population at NJIT facilitating the interest among undecided students in this new major.

A project, that leads to an efficient learning experience, should have two important components [2]: it should address a question or a problem interesting enough to motivate the student interest and activities, and the activities must yield the data that can be used to address the question or solve the problem. In this effort, the questions for potential projects arise from the students during the class discussions. Project-driven learning also supports unconstrained but structured learning. Therefore, as in many other cases of project-based learning [3], there are mini-milestones in the form of scheduled discussions with the instructor. At the end of the final presentation of the project, the students have to state if the objectives are met and if they are interested in continuing working on the topic that emerged from the original question. The final project-based learning experience built a bridge between the Mechanical Behavior of Materials and Characterization of Materials courses offered in the following fall semester. Although a formal assessment is unavailable for this 1st course of a new program due to the small class size and no statistical data, an increase in the engagement of the students compared to that in other laboratory courses taught by the same instructor was pronounced. It is this clearly visible engagement of the students that encourages the author to share this approach within the professional community. Based on the initial positive experience, this work-in-progress will be continued in the following semesters, providing more data for the formal assessment of the learning outcomes.

Technical approach

a. Selecting student questions leading to the project topics

The "Mechanical Behavior of Materials" course is structured as a combination of lecture and laboratory components. The lectures take the form of active discussions on topics. The instructor preliminarily prepares a series of questions that, when answered, cover the theoretical portion of the class. In class, the instructor asks a question, and students provide answers initiating an instructor-guided discussion. The experience shows that this format prompts an increasing number of questions coming from students. Some of the questions are driven by the students' curiosity and may or may not advance the planned topic coverage. Other questions may touch upon a deeper context and may be answered using experiments accessible to students. The instructor's role is to recognize the latter type of questions and navigate the discussion so that some of such "good" questions can be reformulated into the goals for the potential class projects. So far, simple criteria have been used to select the questions:

1. The topics should be related to the mechanical behavior/properties of different materials so that the students learn new things from each other during peer-to-peer presentations.
2. Testing working hypotheses would require at least one material characterization technique that was not taught in the current course.
3. A project can be completed within one month, with 10 hours of laboratory time to experimentally test the working hypothesis.

It is assumed that the instructor is familiar with the instrumentation, equipment, and materials characterization capabilities available within the program. The instructor may have access to additional resources available in the research laboratories and help students utilize such resources and connect with the respective teams of researchers for more in-depth help.

Each selected, formulated in-class question is formally added to the list of potential project topics announced to the entire class. The total number of such project topics increases as the semester continues. Because a student may ask multiple "suitable" questions, the number of potential project topics may exceed the number of students (or student teams) so that a project selection can then be offered.

The following were the questions originated by the students and chosen for potential project topics offered to my class in the spring 2024:

1. How can we measure a strain on the steel sample if the deformation is so small?
2. Is a grain in the metal a single crystal?
3. How are the metals in the strip joined together?
4. Are thermal shape memory and mechanical shape memory the same phenomenon?
5. Do properties of HDPE other than strength depend on the strain state?
6. Does a glass phase make alumina ceramic stronger?
7. What material is the strongest in the braze joint: ceramic, braze alloy, or metal?
8. What will be the mechanical strength of the rubber if we add 50 volume % ceramic filler?

One month before the semester ends, the students pick a project from the list.

b. Developing working hypothesis

Once the project is assigned, the instructor offers a prompt: “Let’s find out!” This starts the process of developing a working hypothesis. The Socrates method is used consistently to lead the students to a sensible working hypothesis. Further, an experimental approach is discussed that can be used to answer their question. The transition from a guess to the development of a hypothesis or/and experimental approach is emphasized. It is important to highlight in the class that both the working hypothesis and experimental approach belong to students. The students thus feel that they “own” their projects, making them both more interested and more responsible. It is also important that these initial discussions occur in class, so that all students are engaged, not only those assigned to the project being discussed.

Results and Discussion

a. Project-led and project-based learning experience

Since time for the final project is limited, it is important to have milestones. A student is required to meet with the instructor weekly to discuss the progress and plan. However, once the “Let’s find out” approach to the project selection was implemented, all students requested to have at least two weekly meetings with the instructor. This served as clear evidence of interest and engagement of the students with the course material. The first, planning stage included the initial discussion with the instructor and a literature search. This stage was completed, as was required, in one week. The following two weeks of the class were fully dedicated to the completion of the experimental part of the projects. Students used the assigned class time for the experimental testing of the working hypothesis and any additional experiments. Such additional experiments could be suggested based on the discussion of preliminary results and observations. Such discussions were highly encouraged. Indeed, multiple additional experiments were offered by the students. The students took advantage of the availability of the laboratory during the off-class time and could be found in the lab quite often during those two weeks. Once again, their presence in the labs outside of the regular scheduled class times signaled interest and motivation. The final week of classes was used for the final discussion and for preparing the project reports. The final project reports were submitted by the end of the semester. An oral presentation in front of the class was used and graded (along with the submitted report) instead of the final examination. The students prepared well-motivated and documented reports and expressed significant interest while listening to the presentations of their peers.

b. Examples of projects

Questions 3, 4, 5, and 8 from the list above were selected by students in Spring 2024.

A discussion in class leading to question 3 started prior to the demonstration of a bi-metallic strip. The discussion started with questions on the bending of a single metal beam and the relationship between the displacement under the weight at the free end of the beam, the geometry of the strip, and Young’s modulus. The discussion relied on reviewing the materials, which the students learned in a previously offered “Engineering Mechanics” course. In the demonstration, a mass was placed on a free end of a metal (actually, a bimetallic) strip. Students were asked to estimate a displacement for a 500-micron thick Invar strip 0.1cm x 40 cm with a load of 100 grams at its end. It was further discussed whether the displacement would change as a function of the temperature of the metallic strip. Each suggestion by students was followed by discussing relevant "How?" and "Why?" Then the behavior of the bimetallic strip was demonstrated experimentally. The observed effect of temperature could not be explained assuming that the strip was made of a single metal. One of the students suggested that the strip consisted of two different metals. Configurations of the bimetallic strip involving different metals clipped together either at one end or both ends reacting to a load attached to a free end were discussed as well. The following in-depth discussion considered mechanical stress due to a mismatch in the thermal expansion coefficients of metals. Then a question was asked: "How are the metals in the strip joined together?" – Let's find out. This simple question led to a final project designed by the student, see Fig. 1. It included verification of Timoshenko's equation that relates the curvature of the bi-metallic strip to temperature. The thickness of each metallic member was determined using optical microscopy of a cross-section of a small piece cut out from the strip. Young's moduli were determined for copper and Invar: the metals used in the strip based on its manufacturer specification. The student operated a box furnace, learning first to program it, and observed the deformation simultaneously using an infrared camera to verify the temperature of the strip. A disagreement between the measured and predicted curvature values was resolved when the actual composition of "Invar" was determined using energy-dispersive spectroscopy (EDS, a new characterization technique). The primary question "How are the metals in the strip joined together?" was answered using SEM. In addition, the student acquired preliminary knowledge about diffusion bonding.

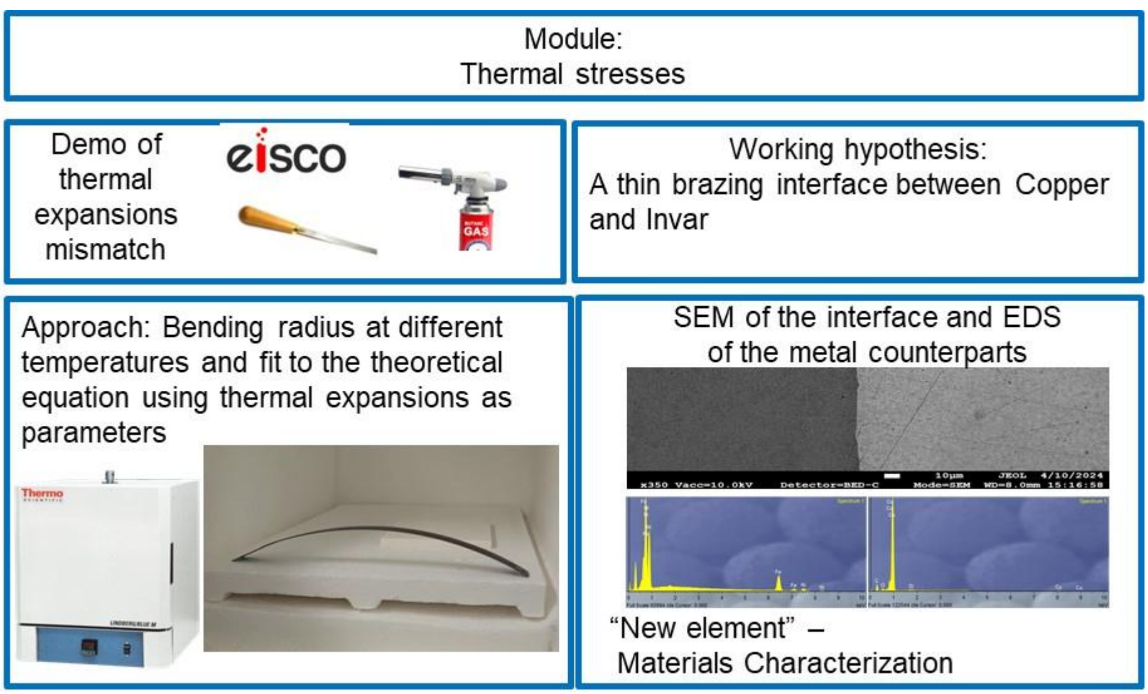

Figure 1. Thermal Expansion: Analysis of Bi-metallic Strip Bending

Other project examples are summarized below.

Example 2. DSC analysis of non-strained and strained high-density polyethylene (HDPE) samples

Course module: Mechanical Behavior of Polymers

- Presentation of laboratory test results to peers: Stress-strain behavior of HDPE at different strain rates. Class discussion of various properties of HDPE and dependence of properties on macrostructure.
- Original question from a student: "What other properties of HDPE (besides strength) depend on the strain state?"
- Working hypothesis: the melting point of HDPE after the test is higher than the melting point of HDPE before the test

Final project *(*Figure *2)*

- Subject HDPE samples to tensile stress at different strain rates (~ 65 and ~165 mm/min average)
- Assess the effect of deformation on the thermal properties of HDPE using DSC

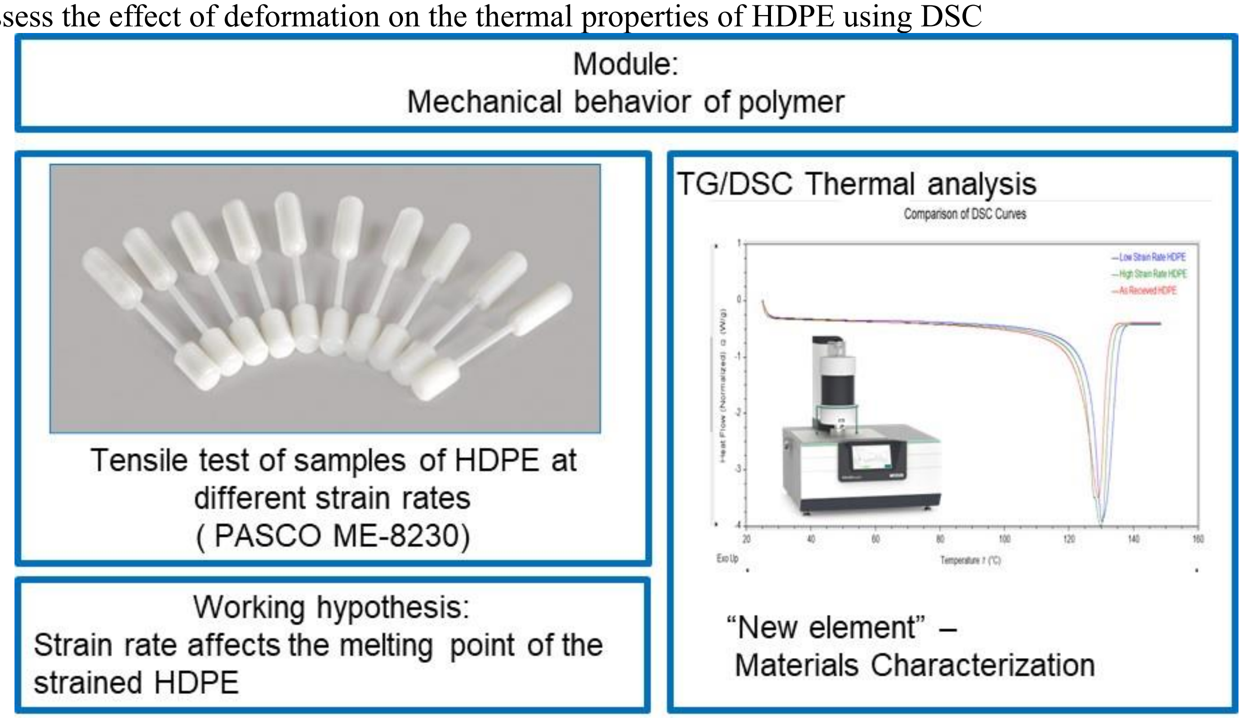

Figure 2. DSC Analysis of Strained and Not Strained HDPE Samples

Example 3. Testing Mechanical Properties of Silicone Composites

Course module: Mechanical Behavior of Composites

- Class Discussion: Similarities and differences between the design of alloys and composite materials

- Original question from a student: "What will be the mechanical strength of the rubber if we add 50 volume % ceramic filler?"

Final project (Figure *3*)

- Formulation of the composite material and casting of the samples (Sylgard 184 with Al2O3 and BN).
- Measurements of Shore hardness.
- Measurement of sound wave propagation speed to correlate with the amount of the filler (using a unique research apparatus developed at an NJIT lab).
- Can we predict Young's modulus of particulate composites (Einstein's equation for prediction of Young's modulus)?
- SEM of the sample to assess the uniformity of Al_2O_3 filler distribution

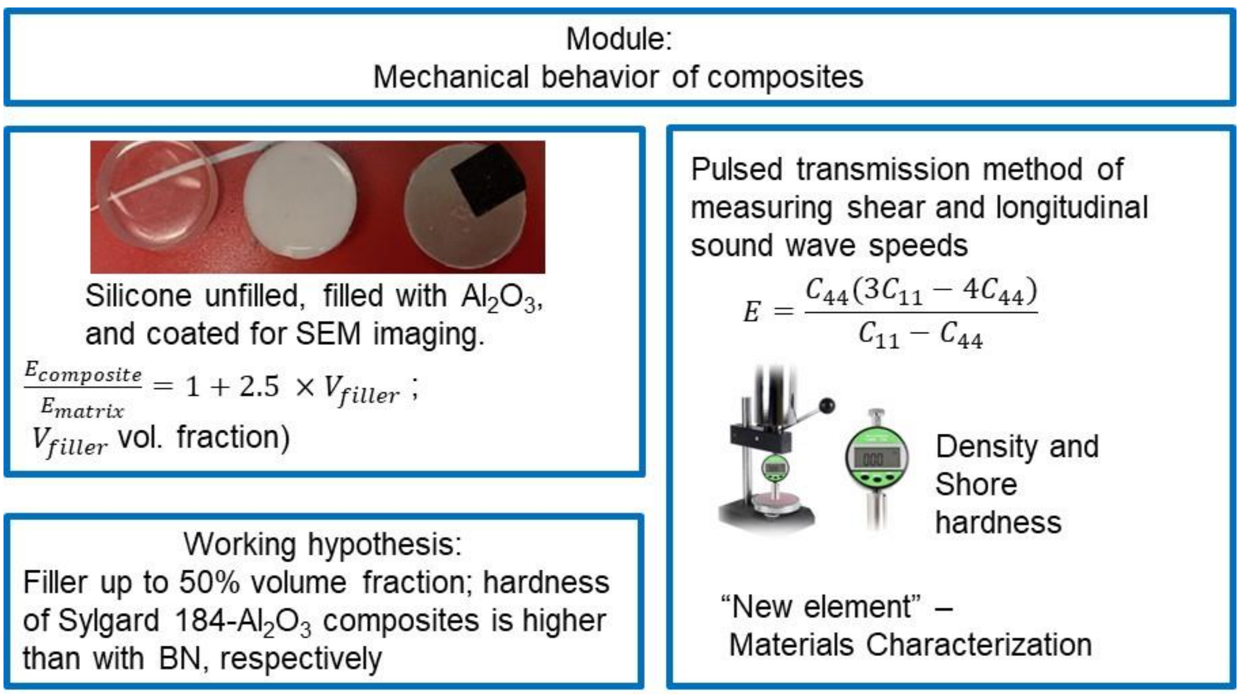

Figure 3. Testing Mechanical Properties of Silicone Composites

Summary

The "Let's find out" project design has grown from questions students asked in class. This method of engaging the students in the design of their own original experimental work was very well received by all students in my Spring 2024 class. It demonstrated that the transfer of project ownership to the students promotes their creativity and makes them responsible for planning and meeting the course deadlines. Although each of the final projects had similar requirements, the topics were diverse. The breadth of topics selected for the student's work and presentations stimulated active knowledge sharing and inspired students to ask questions. In addition, the introduction of a "new materials characterization technique" requirement for each project made students excited and better prepared to take a class on "Materials Characterization" offered during the following fall 2024 semester. I plan to continue developing the “Let’s find out!” approach in all my following classes combining lecture and lab components in the material engineering curriculum.

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