Interactive and Collaborative Materials Science and Processing Course with Integrated Lab

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Introduction

Research has established that learning is dramatically improved when lessons include hands-on practice and application. Laboratory activities are perhaps the deepest application common to engineering curricula. In the fall of 2016, Campbell University introduced a general engineering program that incorporates project-based courses throughout the curriculum and teaches most engineering courses in a Classroom Laboratory (ClassLab), blending the content-focused (lecture) and hands-on (lab) aspects of engineering classes into a seamless course offering. The first Materials Science and Processing course was first taught in the fall 2017 semester. This course mixes just-in-time lecturing with laboratory activities in three weekly 110 – minute sections. Five hands-on labs guide the course interspersed with weekly problem-based assignments, peer instruction, and a symposium-style poster presentation for the final project. Learning outcomes for the course include the technical Materials Science and Processing knowledge as well as writing laboratory and research reports, developing experimental procedures, and gathering data to form conclusions. Using the ICAP framework developed by Chi & Wylie, many of the course activities are designed to fall within the Constructive and Interactive modes of engagement.

Background

The Interactive>Constructive>Active>Passive (ICAP) framework can be used as a lens to understand how various aspects of a course engage students and contribute to cognitive engagement and learning. ICAP is a way to further define the broader area of "active learning" to more specifically connect student actions and the cognition that these actions are likely to prompt [1]. ICAP stands for *Interactive*, *Constructive*, *Active*, and *Passive*, the four modes of student engagement that are defined through the framework. When these words are used to refer to the modes of cognitive engagement, they will be italicized. *Passive* student engagement is recognized as a state when students are simply receiving information. It can happen when students are listening to a lecture without additional engagement, reading a passage of text, or engaging in any learning activity where they are observers and take no actions to engage with the material. *Active* student engagement is seen when students are manipulating, or taking some action related to the content. This could be as simple as taking verbatim notes in a lecture, highlighting while reading a text, or manipulating an object in a classroom or laboratory setting. *Constructive* student engagement is when students generate new content, taking the content that they are given and manipulate it such that they are including new ideas that go beyond the given information. Students in this mode of engagement may take notes in their own words, ask questions to probe the information more deeply, or connect new information to existing information. *Interactive* student engagement happens through dialoguing when more than one student is contributing to the conversation in a *constructive* manner. Discussing similarities or differences, working within a group to address a problem or debate a topic, or elaborating on the contributions of others are examples of likely *interactive* engagement. For student engagement to be *interactive*, it must include an interactive dialogue where each student contributes *constructively* with enough frequency to have multiple *constructive* additions during the dialogue.

The ICAP framework will be used to describe the various components of the course. This course was developed to incorporate a variety of evidence-based practices to encourage cognitive engagement from students throughout the semester.

Course Description

This is a ClassLab, designated by the time allowed for class and the space where class is held. Rather than a separate class and laboratory or recitation, the four credit-hour class meets for six hours per week and combines the content and hands-on aspects of the class. A maximum of 24 students are in each section. Within the six weekly hours of class, students take part in a variety of learning experiences ranging from lecture or videos to collaborative learning and hands-on work using the laboratory equipment. Aspects of the class will be discussed using the ICAP framework. Specific areas that can be applied in other courses are addressed in the Implications section.

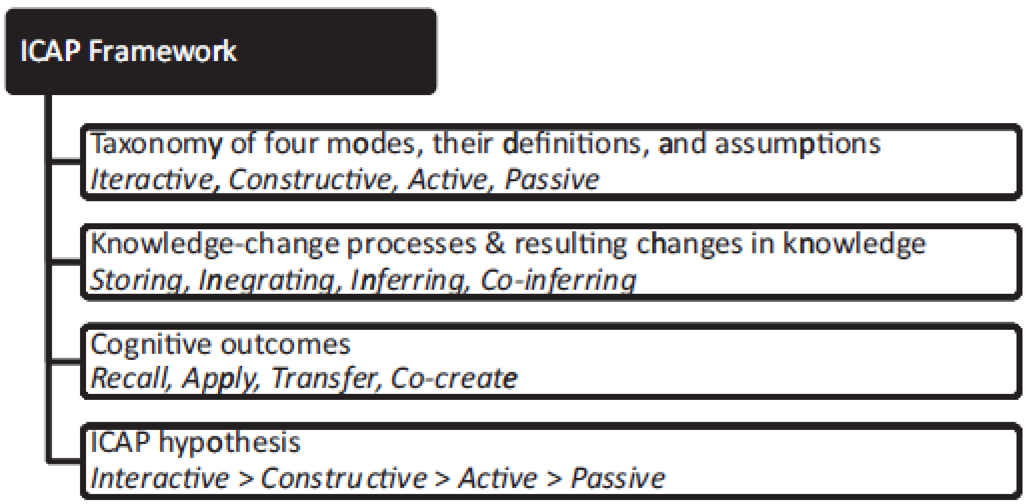

Figure 1. ICAP Framework components [1, p. 221]

Passive

As with all courses, it is difficult to ensure all students are engaging in active learning at all points. There are times when the instructor is explaining a technique or concept and students may not be taking notes. Students may be asked to read something and do not engage anything but their eyes. A video or simulation may be used to demonstrate a concept and students may not develop questions related to the content. All courses will have some *passive* components. One of the aims of this course is to minimize the *passive* and to facilitate more active engagement from students as often as possible.

Active

In this course, there are a number of concepts and techniques that are presented in a way where students are likely to engage in an *active* manner. In an introductory materials science course, there are a number of charts, tables, and graphs that are new to students. When the content is presented in class, these concepts are often given in a "notes with gaps" format. For example, when defining phase diagrams and the components seen in phase diagrams, a handout is given to the students with four different diagrams. These diagrams are minimally labeled. Throughout the discussion, students are expected to *actively* engage by annotating the graphs.

Using the equipment in the laboratory also requires *active* engagement. Students are told how to use the equipment but must physically prepare their samples, use the microscopes to gather data, and set up the equipment to work with their samples. Overall, they are not generating new information while working in the laboratory in the sense of creating new techniques and methods for handling samples and equipment, they are simply following procedures that they have been shown. The act of using the equipment, handling the samples, and at times, reminding each other the proper procedures, is *active* engagement.

Constructive

The largest area of *constructive* student engagement is the just-in-time, problem-based learning model used for the majority of course content. Students are given a set of problems before they have learned all of the required content. Wherever possible, the problems incorporate a number of ideas relating to materials science and are more strongly design-oriented problems. Often this is achieved by adding to problems provided in the textbook rather than developing new problems from the ground up. Students are expected to outline the solution process for their problems in a proscribed engineering format. They must then bring content-focused questions to the class in order for the instructor to discuss the content they need to understand.

A typical class begins with a concept question or short problem to solve related to content that has recently been discussed or has been found to be difficult through either recent assessments (e.g. exam, homework, etc.) or the instructor's experience. This initial question prompts students to take the information they have learned and to apply it in a problem or to reconsider it in a new way, *constructing* in their engagement by adding new knowledge to the content provided.

Interactive

Due to the requirement of *constructive* dialoguing, it is difficult to be sure that all students are engaging in an *interactive* way. Scaffolding activities that incorporate discussion and encouraging the quieter students to contribute to the pair or small group discussions are ways that a faculty member can work to foster interactive engagement in their classroom.

In this course, approximately every other week students are assigned a jigsaw activity. To more deeply incorporate the "processing" content of the materials science and processing course, the processing methods are generally covered through these jigsaw assignments. In a jigsaw activity, students are placed into groups of four (in this course) and are instructed to number themselves based on something fairly arbitrary (e.g. favorite Dwarf from Snow White and the Seven Dwarfs, time they woke up that morning, favorite color (ROYGBIV), etc.). Each number corresponds to a specific processing method in the overall topic (e.g. for cold processing, students learn about strain hardening, cold forging, etc.). The student must then learn about the assigned topic and explain it to their group, including a video that they have found online to illustrate it. This part of the activity tends to be *constructive* for the student as they present their research in their own words and either *passive* or *active* while not presenting. The interactive component comes into play in two specific aspects. Students are instructed to develop an exam question related to their topic and have their group members discuss what the answer should be, ideally prompting *constructive* dialogue among the group. Students are also asked to apply their processing method to a specific material or desired outcome. For example, when discussing cold processing methods, they discuss alpha brass (the material used in the corresponding laboratory experiment) and how this material would act if used in their assigned processing method. The students are expected to discuss the similarities and differences between their methods, again prompting (but not guaranteeing) *interactive* engagement.

Students are also given the opportunity to engage *interactively* through their laboratory experiments. Once their data has been collected and initial analyses are complete, students are given time to share their findings with other groups and to discuss what conclusions they can make based on their materials science knowledge and the data they have gathered. Students are in teams of three or four when collecting data. After data is collected, the student teams are shuffled such that each student in a new team was from a different data collection team. In their new teams, students share their results, comparing their data, data collection techniques, possible sources of error, and likely conclusions. For some experiments, their conclusions should be similar but for others, each group may have a different sample and is therefore able to have a more in-depth discussion justifying their conclusions in reference to the other conclusions presented in the dialogue.

Conceptual questions that are expected to prompt *interactive* engagement are also asked, typically one per class session, often at the beginning of the class or after reviewing specific content. Students are instructed to take part in a Think, Pair, Share exercise where they are given a period of time, typically up to a minute, to consider the problem, then are expected to discuss (ideally in *constructive* dialogue) with someone near them, and finally share their responses as a class. Student questions that arise organically are sometimes also turned back to the class in impromptu Think, Pair, Share activities that allow students time to consider the problem and have the added benefit of giving the instructor some time to dialogue with some groups of students or to quickly look up a reasonable response if the question was completely unexpected.

It is also hoped that students engage *interactively* while completing laboratory assignments and their final project. Student groups are often rearranged throughout the semester to encourage new interactions and sharing of ideas with others. In all of these situations, it is possible for *interactive* student engagement to occur, but it is also possible for students to simply parrot what they had read or heard (*active* engagement), one student to dominate the conversation (*constructive* engagement for only that student), or for students to not adequately engage with the material. In this course, the instructor takes on the role of prompting students to *constructively* dialogue in addition to providing scaffolding and opportunities for *interactive* cognitive engagement.

Additional Student Motivation

In addition to engaging students cognitively using the methods outlined above, student motivation to engage with the course materials is improved through student choice. The object used in student projects is freely chosen by students wherever possible. For example, one of the labs is one where students are expected to bring in metal objects that are broken to explore failure in metals. Any broken object is reasonable, so students are able to bring in items that may have some interest to them. For example, we have had broken gears, broken brackets, and broken screws, all items that students felt should not have broken when they did and were therefore interested to learn more about how that item may have broken from a materials science standpoint.

The final project allows for a similar choice for students. They are instructed to choose any implement or tool, again made from metal, to consider. They will consider the engineering criteria and constraints that would go into the design of the item as well as what materials they might choose to make the item and what processes they would consider reasonable. They will then destructively test a sample using the techniques they have learned throughout the course and research the object in an attempt to discover what material was used and how it was processed. Students work in teams, writing a final report and presenting a poster in a symposium-style final presentation to share their findings. Students co-create the poster rubric to encourage a greater sense of ownership and understanding of the project requirements as an in-class activity as well.

In addition to student choice, labs are tailored to fit the number of students and require all students to take part. Each student is expected to make a specific number of samples. Student teams are commonly three or four students. The number of final samples required for their reports may vary based on the number of students in the team, but each student is responsible for the preparation and data collection for the same number of samples. In this way, all students are expected to use all equipment and to gather information first-hand while also keeping the overall work equal no matter how large or small their team may be.

One final method for increasing student motivation in the physical experiments is the steel lab. Students can take part in the process of quenching samples of steel that will be used in the experiment. Watching the steam rise from the quench buckets and feeling the heat from the red-hot steel samples in the furnaces increases student excitement for the lab. Students are then given an unknown sample and must develop an experimental procedure using their knowledge of materials science and the laboratory equipment to determine whether the sample was slowly cooled, quenched, or tempered, and what general grade of steel it is, high, medium, or low.

Beyond student projects, student motivation is addressed by having all students complete a reflection question at the beginning of the term. Students are asked what question they would like answered through the course and what area of interest they have relating to materials science. The instructor is able to skim the responses and to draw upon examples relating to these areas throughout the course, helping students to connect their interests and questions to the content.

Implications

The course described has a number of advantages that do not necessarily occur in all institutions. Sections are capped at 24 students. The equipment is in the room so that there is no separation between the lecture and laboratory or recitation. There are no TAs leading the course in a typical semester. The four-credit course meets for six hours per week. These advantages mean that it would be difficult for this course to be implemented in the same manner in many other institutions. There are, however, a number of aspects of the course that could be implemented in traditional lecture spaces and even large classrooms.

Beginning the class with a conceptual question or a short problem for students to solve is easy to integrate for any size class. For conceptual questions, the AIChE Concept Warehouse [2] has a number of concept questions that can easily be presented to students to gather real-time data in a classroom of any size. Students must sign up for an account but can access their account from any device. The same website offers a Materials Science Concept Inventory for additional data collection and review of student misconceptions. Poll Everywhere [3] is another service that can allow you to present clicker-style questions to your class through a PowerPoint slide, seamlessly integrating into your lecture. Your institution may provide other similar resources.

Having students teach each other through jigsaw activities can be implemented in a classroom of any size, though it is much easier to use if you have a number of TAs to monitor student participation. In this course, student participation is also encouraged by requiring students to upload a short report on the research they did as an assignment and including questions on the exams related to the content they were expected to cover. Think, Pair, Share (TPS) activities are similarly easy to implement in any size class, but again, it is easier to ensure compliance in larger classrooms if there are enough TAs to monitor and interact with reluctant groups. More details about jigsaws and TPS activities are given below.

Jigsaw

Jigsaws are a technique where each student in a group is responsible for a specific part of a project or activity in order to complete the activity; each team member has their own piece of the puzzle and is needed in order to complete the final product, hence the name jigsaw [4, pp. 253-254]. This technique can be used in a classroom with any number of students. Groups can be formed for the entire semester or in the case of a number of smaller jigsaw activities throughout the course, re-formed as time goes on. In this class, jigsaws are used to cover the various ways of processing materials, from hot- and cold-working methods to the processing of ceramics and polymers and common machining methods. To prepare, the students are expected to research a processing method, answer specific questions related to that method, provide a short video illustrating the process, and develop a reasonable exam question related to their topic. Students are split into teams of four where each person has a different topic. Where there are missing members or teams of fewer than four, I either share the missing information with the group or have a student from another team present to two teams simultaneously. In their teams, the students take turns discussing their material and sharing their videos. The final question they are asked to research is something that they can discuss as a way to compare and contrast their individual topics in an interactive manner. A rubric for the ceramics processing jigsaw can be seen in Figure 2.

Grid View | List View

	Novice	Competent	Proficient
Video	**0** (0.00%) Less than 30 seconds, more than five minutes (without marking relevant parts) or does not relate to the assigned process.	**3.125** (12.50%) Between 30 seconds and five minutes and somewhat related to the assigned process.	**6.25** (25.00%) Between 30 seconds and five minutes and shows a good overview of the entire assigned process.
Exam Question	**0** (0.00%) No question given or not related to the assigned process.	**3.125** (12.50%) Simple fill-in-the-blank or multiple choice question provided related to the assigned process.	**6.25** (25.00%) Detailed fill-in-the-blank question (multiple relevant blanks), complex multiple choice question, or other reasonable question related to the assigned process.
Explanation	**0** (0.00%) No explanation given.	**1.25** (5.00%) Less than a paragraph or explanation not relevant to the assigned process.	**2.5** (10.00%) One paragraph to two pages of explanation on the assigned process.
Uses	**0** (0.00%) No uses related to the assigned process.	**1.25** (5.00%) Up to two uses or uses not related to assigned process.	**2.5** (10.00%) More than two uses related to the assigned process.
Method	**0** (0.00%) No description of the assigned process.	**1.25** (5.00%) Description incomplete or not related to the assigned process.	**2.5** (10.00%) Full description of the assigned process.
Material Effects	**0** (0.00%) No description of the effect on materials by the assigned process.	**1.25** (5.00%) Description of only micro or macro effects or description not relevant to assigned process.	**2.5** (10.00%) Description of micro and macro effects of assigned process.
Types of Ceramics Discussion	**0** (0.00%) No mention of which ceramics can be used.	**1.25** (5.00%) List of ceramics that can be used but not rationale.	**2.5** (10.00%) List of ceramics that can be used and reasons why those ceramics can be used in assigned process.

Name: **Ceramic Processing Jigsaw**

Description: **Assignment must include: Which process was assigned. Reasonable exam question related to assigned ceramic process. Video link to explain assigned ceramic process. Narrative of one paragraph to two pages describing the full ceramic process, what effect that process has on materials, common uses for the process, and what ceramics can be used in the process.**

Figure 2. Ceramics processing jigsaw rubric

Think, Pair, Share

Think, Pair, Share activities can be used to ensure that all students are considering questions posed to the course rather than waiting for those one or two individuals who usually answer to provide a response or for the instructor to choose a random student. Just like the title says, students are asked to think about a question, discuss it with a student nearby, and then share responses with the class as a whole. This works well with conceptual questions but can be used with any type of question in a course. To implement a TPS activity well, it is important to focus on the initial “Think” stage. During this stage, students should be considering their individual response to a topic and writing down their answers. Adequate time should be given for students to consider the question and come up with a response, typically a full thirty seconds to two minutes, and silence in the room should be enforced. This allows all students to engage with the question and allows for reflective learners, those students who learn better when they have time to sit and think about the content, a chance to use their preferred learning method during class time. Students then discuss their responses with a neighbor, and then responses are solicited from the class as a whole. To ensure all students are keeping up with the problem, it is reasonable to randomly call on students as at this point, everyone in the class has had a chance to consider the problem and talk with a neighbor so should have a response ready to go [4]. This works with any number of students in large or small classrooms.

References

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[4] R. M. Felder and R. Brent, Teaching and Learning STEM: A Practical Guide, Jossey-Bass, 2016.