Content, Assessment, Pedagogy: A Materials Engineering Course

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Using an approach where content leads to assessment leads to pedagogy, a steel course is developed using a backward design model that centers on the work of the practicing materials engineer.

Abstract

While the temptation for an instructor might be to "Teach the Text", a better plan is to start by determining the course objectives. By employing a backward design sequence of first identifying the content, then the assessments, then the pedogy, the instructor has the opportunity of teaching students what they need to know about the subject. An example of a materials engineering technical elective course targeted to seniors is used as an example. Tools designed to assist the instructor in course design are presented. In the case of Content, tools such as Enduring Understandings, Learning Objectives, Difficult Concepts and Concept Maps are presented. In the case of Assessment, tools such as the Assessment Triangle and Rubric are presented. In the case of Pedagogy, tools such as Stepwise Design and Case Studies are presented. Examples are provided that were used in the design of the steel course.

Background

When challenged to develop a course, the first temptation might be to select a textbook. The second temptation might be to "Teach the Text". Edmund Hansen in *Idea-Based Learning* (Hansen, 2011) describes what he calls 'The Traditional Course Design Model' which consists of

(1) selecting content,
(2) assignments,
(3) grading,
(4) determine objectives (from course topics).

A couple problems are manifested with this approach. The first is that the content will direct the objectives. By following the text, the instructor is along for the ride the same as are the students. The objectives for the course emerge as the course develops over the semester. The second problem is that most textbooks contain more information than can be presented in a single course; or as Hansen states "textbooks have too many chapters" (Hansen, 2011, p. 14). A different approach to designing a course is proposed by Wiggins and McTighe in *Understanding by Design*. Wiggins and McTighe make the distinction between "logic of the content itself" which is the basis of the traditional course design and "logic of learning content" which considers the needs of the students in their learning journey to alternate between details of the concept and how those details fit in the big picture (Wiggins and McTighe, 2005). By following this logic, the instructor would first determine the course objectives first, not last.

In 1949, Tyler proposed the concept of taking a backward approach in which the desired outcome of the course would be the initial consideration (Tyler, 2013). Hansen acknowledged Tyler's contribution by labelling his preferred approach to course design as "The Backward Course Design Model" (Hansen, 2011, p. 22) which consists of

(1) Content: determine objectives first, then content
(2) Determine acceptable evidence,
(3) Plan main learning experiences, and
(4) Sequence course content around activities

As shown, determining course objectives is the last step in the traditional design as opposed to the first in the backward design. In the structure of the paper that follows, Content is step 1; Assessment is step 2; and Pedagogy is steps 3 and 4.

This paper will present the application of backwards design to an upper class materials engineering course on steel. The problem of too much material can be illustrated in steel when considering the subject of stainless steel. Stainless steel is a subset of steel that involves a considerable amount of content in order to convey the distinction between it and conventional steel (i.e the effect of chromium on the size of the austenite phase field). It is a difficult concept to convey and one which may take a sizable investment of time to teach well. If it is clearly stated as a course objective, then the instructor can follow the course design that would include assessments and planned learning experiences. However, in the absence of clearly identified desired results stated at the start of the design process, the instructor may find that it is included in the content of the text and, by default, may start teaching it without having thought through the content, the assessment and the pedagogy. However, if stainless steel is not clearly targeted as a desired result, then the subject can be omitted without concern that students aren't getting everything possible from the course. In any one course, it isn't possible to cover (get) everything. The key is first deciding on the results and content, then determining the assessment, then planning the learning experiences, the sequence and delivery.

Content

A materials engineer in industry is largely a problem solver. The challenge is to understand what the properties the customer needs, translate the property needs into a desired microstructure, design the process to deliver it and diagnose the cause when it does not turn out as planned.

Wiggins and McTighe offer a definition of what they call Enduring Understandings as, "what do we want students to understand and be able to use several years from now, after they have forgotten the details" (Wiggins and McTighe, 2005, p. 342). With that perspective, the steel course has two Enduring Outcomes.

1. As process leads to microstructure leads to properties is the foundation of Materials Science and Engineering, the foundation of the course will be on microstructure. Understanding the property to microstructure relationship and the process to microstructure relationship is foundational to being a materials engineer.
2. Materials Engineers are problem solvers who analyze the difference between the expected and the actual microstructure to diagnose what may have happened in the process to explain the difference.

The validity of these Enduring Understanding was checked with a Chief Materials Engineer. Upon reflection, he verified the application to the practicing engineer by concluding, “This is our life” (Bill Steen, personal communication, March 23, 2014).

Learning objectives (referred to as Learning Outcomes by Hansen, 2010) are concrete performance tasks that students should be able to perform that demonstrate an understanding of the Enduring Outcomes. Hansen states that Learning Objectives should (1) be student focused, (2) emphasize higher-order thinking skills, (3) measurable, and (4) concrete. All of the learning objectives support these two outcomes. The Learning Objectives for the steel course include:

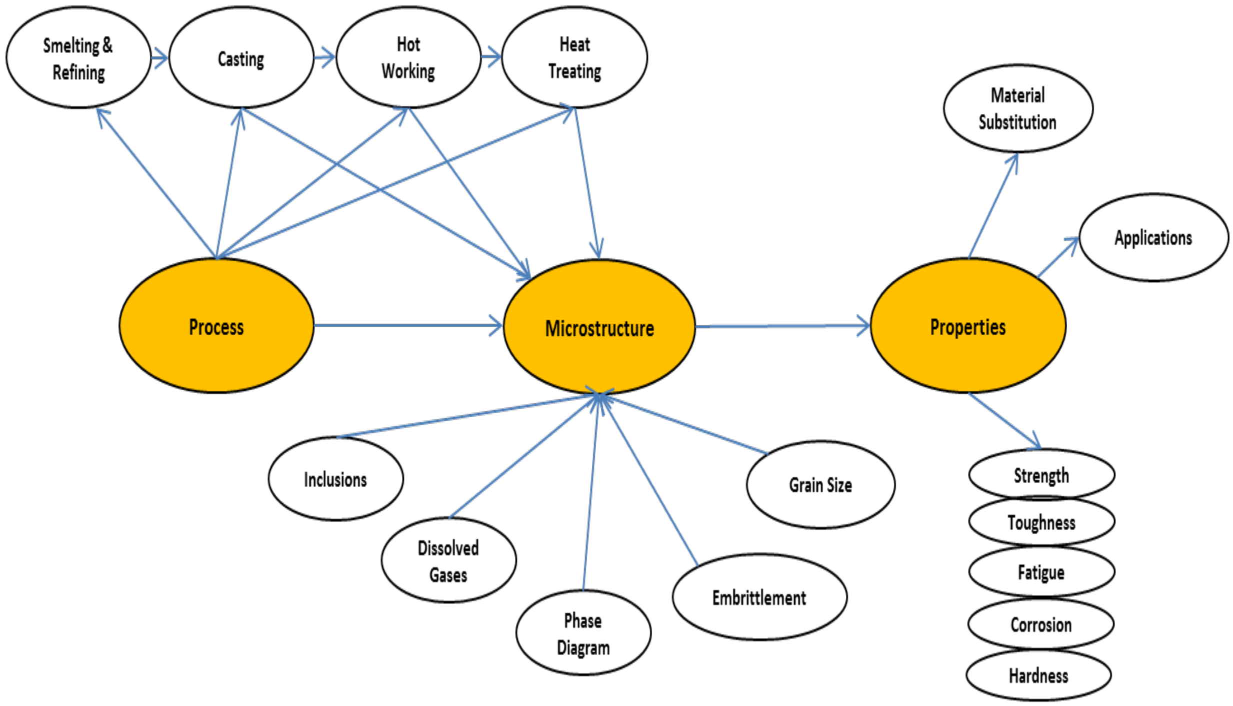
1. Students will demonstrate the ability to draw a representative steel microstructure and label phases in the microstructure with attendant composition of the phases.
2. Summarize the steel casting process and describe the microstructural effects.
3. Describe the reason various types of impurities occur in steel and the effect on processing, microstructure and properties.
4. Employ the lever rule to calculate phase concentrations from composition and temperature on a phase diagram.
5. Determine the phases produced from a thermal history as shown on time-temperature-transformation and isothermal transformation diagrams.
6. Interpret what steel grades would be appropriate for a given application based on material properties.
7. Apply the partition coefficient to understand how microsegregation can result in a eutectic composition at a grain boundary.
8. Propose why, what and how practicing engineers develop or modify thermal treatments in order to obtain a desired microstructure.
9. Describe how grain size provides the primary strengthening mechanism for low alloy composition steels.
10. When presented with an actual photomicrograph of a steel structure as well as the expected photomicrograph, students will be able determine what went wrong in the process that would account for the difference in structures.

Difficult Concepts

The first Enduring Understanding is to describe the structural knowledge required to recognize first the relationship between process and microstructure and second the relationship between microstructure and properties. One of the primary difficulties is that microstructures cannot be seen without the aid of magnification. As such, students have difficulty making connections as they do not have prior learning or concepts. According to A. H. Johnstone (1991), University of Glasgow, "Many of the concepts of science don't present themselves for selective observation (as they are not readily observable). Nothing can be pulled out from long term memory experience to provide either the means of matching or provide anchorages for the new ideas to be filed away in long term memory." When describing this lack of connection specifically for Materials Science and Engineering (MSE) Krause, et al (2010) state "…in MSE, there is difficulty in learners constructing a useful conceptual framework to effectively link the concrete 'macroworld' of everyday objects and phenomena to the abstract 'nanoworld' of atoms, molecules and microstructure which actually control material's properties." From my experience, this difficulty is manifested by both students and practicing engineers (who might have failed to learn, but at least fail to apply the concept) skip the microstructure component and go directly from process to properties. Understanding the connection of the macro world of properties to the micro world of microstructure is fundamental to understanding the course. It is critical that students learn the importance of microstructure to the determination of properties. As such, the microstructure to property connection will be the fundamental assessment made throughout the course. If students do not understand the link between microstructure and properties, then they will not be successful.

Concept Map

Novak and Cañas in *The Theory Underlying Concept Maps and How to Construct and Use Them* (2008) propose using concept maps as a way of organizing and representing knowledge. A concept map helps to visualize the hierarchy of knowledge and linkage of the concepts. The benefit is the creation of a cognitive structure that helps transition from enduring understandings and learning objectives to how the concepts may be best presented to the learners.



The Assessment

Learning Objective #1 is "Students will demonstrate the ability to draw a representative steel microstructure, label phases in the microstructure with attendant composition". The challenge is to how to assess how well students have mastered that objective.

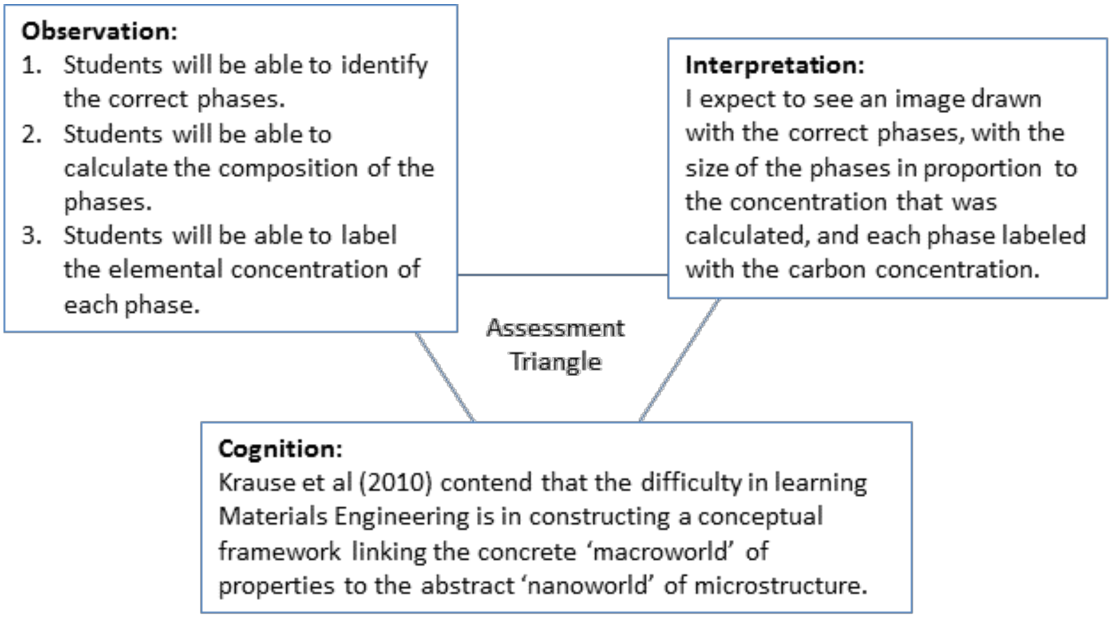
As stated previously, the role of the materials engineer in industry is largely one of a problem solver. A problem exists when what actually occurred differs from what is expected. The primary skill of the materials engineer is to know what is expected. In the case of steel (and many other materials) a microstructure can be predicted based upon composition and thermomechanical history. In most cases, a customer will issue a specification stating the desired properties. The metallurgical engineer will know what microstructure will provide those properties. The next step will be to establish the process steps that will provide the required microstructure. A problem initially surfaces when the actual property test results do not meet those stated in the specification. The first step in diagnosing the problem is to investigate the microstructure. The first step in analyzing the microstructure under the microscope is to determine whether the microstructure is as expected. If not, then the next step is to determine what might have happened in the process to produce the actual microstructure.

This learning objective addresses the first step. It is intended to provide the fundamental understanding needed for the metallurgical engineer to determine how the expected microstructure should appear. It might be easier to ask the student to simply memorize microstructures. However, in doing so, the student will not learn the connection between process and microstructure. It is connection link between composition and thermomechanical processing and the microstructure that makes this task, and the assessment of the task, authentic.

Assessment Triangle

The book *Knowing What Students Know* was the result of the National Research Council's efforts to develop assessment recommendations based on current understanding of cognition. The conclusion is that any assessment is based on three elements (1) cognition (what aspects of understanding are to be assessed), (2) observation (the tasks used to demonstrate understanding), and (3) interpretation (the methods used to analyze the evidence resulting from the tasks) (Pellegrino, Chudowsky, and Glaser, 2001). Pellegrino et. Al. represented the linkage among the three elements as a triangle as it conveys that each is connected and dependent on the other two.

The assessment triangle shown below is constructed to assess the Learning Objective #1.



Objective	Assessment
Students will demonstrate the ability to draw a representative steel microstructure, label phases in the microstructure with attendant composition.	**General:**
	Calculation-type questions, open-ended response
	Claim:
	By providing students with a combination of fundamental principles and case studies, students will be able to determine microstructure from composition and thermal history. The setting is sufficiently authentic that the students will be able to determine microstructures of steel and aluminum in an industrial setting.
	Task:
	1.Use lever rule to calculate phase concentration.
	2.Use TTT Diagram to determine phase morphology
	3.Draw the microstructure
	4.Label the carbon concentration in each phase
	Evidence
	Calculations of phase concentrations, drawings of microstructure and labelling phase compositions will provide evidence that students understand the relation of process to properties.

Rubric for evaluating (grading) the assessment

One of the primary functions for the materials engineer is to understand how the process produces a microstructure. This learning objective tracks the process of taking the composition and the thermal processing and being able to predict the microstructure. This rubric breaks the task into four separate steps. Partial credit is given for the completion of each successive step. The stepwise design means that in order for a student to receive higher credit, the previous step must be done correctly.

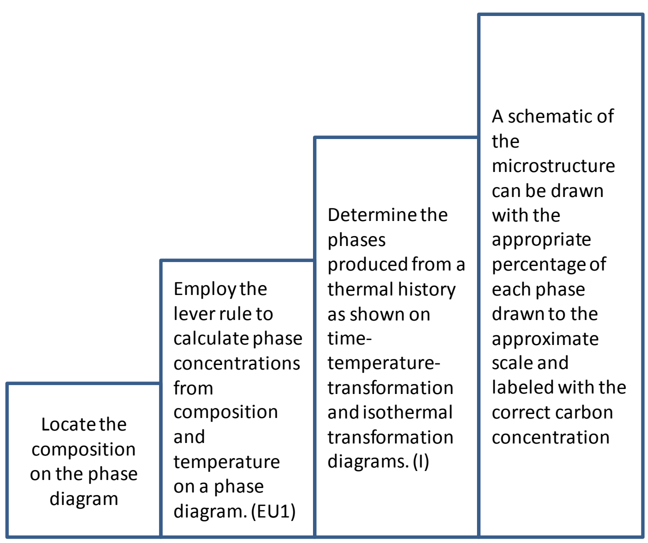
L1. Students will demonstrate the ability to draw a representative steel microstructure, label phases in the microstructure with attendant composition.	100%	75%	50%	25%	0%
	Composition can be identified on the Fe-C phase diagram	Composition can be identified on the Fe-C phase diagram	Composition can be identified on the Fe-C phase diagram	Composition can be identified on the Fe-C phase diagram	Composition cannot be identified on the Fe-C phase diagram
	The Time-Temperature-Transformation diagram can be used to identify phases present	The Time-Temperature-Transformation diagram can be used to identify phases present	The Time-Temperature-Transformation diagram can be used to identify phases present	The Time-Temperature-Transformation diagram cannot be used to identify phases present	
	The Lever Rule can be used to calculate concentration of the phases	The Lever Rule can be used to calculate concentration of the phases	The Lever Rule cannot be used to calculate concentration of the phases		
	A schematic of the microstructure can be drawn with the appropriate percentage of each phase drawn to the approximate scale and labelled with the correct carbon concentration	A schematic of the microstructure cannot be drawn with the appropriate percentage of each phase drawn to the approximate scale and labelled with the correct carbon concentration			

Pedagogy

Problem Solving. A problem often manifests itself as a batch of metal that is failing properties. The metal is produced, sampled, tested and fails to meet specfication. For example, the strength is too low. The materials engineer is notified and expected to perform the diagnostic work to determine the reason for failure. The primary diagnostic tool is the microscope. The engineer looks at a sample under the microscope to determine (1) what is the actual structure? (2) Is the structure what is expected, (3) what is the difference between actual and expected? (4) What could have happened in the process to the metal create the actual structure?

Analyzing the difference between the expected and actual structure is the real work of an engineer. It is the primary role of a practicing metallurgical engineer. The opportunity to make this an authentic performance assessment is that much of the actual work can be done in a classroom environment. Often a metallographer performs the microscopic work and presents the metallurgical engineer with a photomicrograph of the structure. As such, it is not necessary to have the class perform the metallographic work. This can be done off-line so that all of the students can compare the actual and expected photomicrographs and questioned on what could have caused the difference. This can be done in the classroom. As such, an authentic performance task can be conducted in class.

One of the most conceptually difficult steps is to determine what the expected structure should be. In the case of Learning Objective #1, a number of separate concepts need to be brought together in order to be able to accomplish this task. Part of the challenge in this course will be to space the introduction of the concepts in order to sequence the learning to ensure students know the material such that they can put the pieces together in order to determine the expected structure. The learning objectives follow a Stepwise Design as presented by Hansen (2011) on p. 126. The Stepwise design incorporating the Learning Objective #1 is shown below:



Lessons will need to be developed that teach the stepwise progression over sufficient time with sufficient reinforcement to enable the students to thoroughly learn the preceding concept before progressing to the next.

Case Studies. Case studies offer a means of making the content more relevant. Three case studies were used in the course: (1) The conversion of the 2015 F150 body from steel to aluminum (a timely example as this material substitution decision is occurring this year), (2) the potential contribution of the steel to the sinking of RMS Titanic (comparing modern vs. the Titanic steel microstructure should promote an understanding of the effect of microstructure on properties), and (3) The San Francisco – Oakland Bay Bridge hydrogen embrittlement problem (as a section was nearing completion, it was discovered that 32 of the 96 three inch diameter steel rods had failed). All three of these case studies illustrate how Learning Objectives connect to real world challenges.

Summary

The alignment of the class content, assessment and pedagogy is achieved by first being clear about the content. The Enduring Understandings of (1) the crucial role of microstructure in linking process and properties and (2) problem solving through microstructural forensics will serve as a foundation for all the content covered in the course. All of the Learning Objectives connect to the concept of microstructure being the foundation of Materials Engineering in general and of this course in particular. By being clear about the content, the assessment also becomes clear. As each topic is introduced in the context of linking process to microstructure to properties, the learning expectations relative to assessments will also be introduced. Through deliberate, distributed practice which will include deliberate, distributed feedback, students will understand the alignment of content and assessment. Due to the inherent difficulty students have in constructing a conceptual framework linking the concrete 'macroworld' of properties to the abstract 'nanoworld' of microstructure, the microstructure foundation will be repeated early and often. The pedagogy will be aligned through the use of both stepwise design (for concept introduction) and authentic performance tasks (for the case studies). Stepwise design will serve as a structure which sequences the introduction of the content to ensure students have mastered one component before progressing to the next. Deliberate, distributive practice will be incorporated in the presentation of the material. The pedagogy will be further aligned with the content and assessment through the use of case studies. As an example, the Titanic's microstructural story (poor microstructure resulting in brittle steel) intersects with the human interest story (striking an iceberg the night of April 14, 1912 resulting in the loss of 1,500 lives) should provide further motivation for appreciating the Enduring Understanding of linking process to microstructure to properties.

The content, assessment and pedagogy are aligned through the application of backward design. Beginning with the course content, the application of the Concept Map, Enduring Understandings, and Learning Objectives provided the basis of integrating assessment and pedagogy. Assessment Triangles and Rubrics were used to ensure the assessment aligned to the content. The pedagogy was aligned through the use of stepwise design and case studies. The pedagogy addresses materials engineering difficult concepts through both the step wise introduction and the case studies. The incorporation of deliberate, distributed practice will ensure the hard part foundational concepts are learned before introducing more advanced concepts. Finally, the alignment of the content, the assessments, and the pedagogy is supported as both Enduring Understandings really are the ‘life’ of the practicing materials engineer.

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